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BATHYTHERMOGRAPHIC SURVEYS NEAR NAVAL FACILITIES AT POINT MUGU,--ETC(U)
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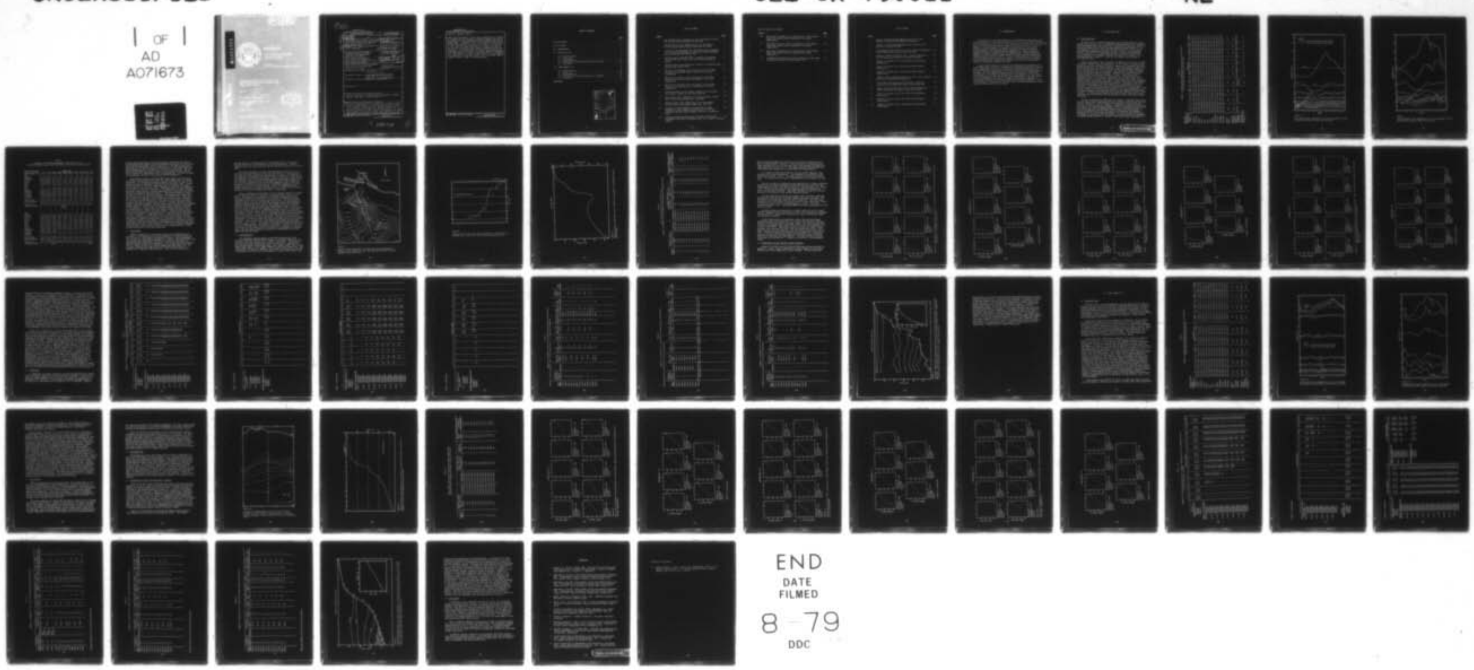

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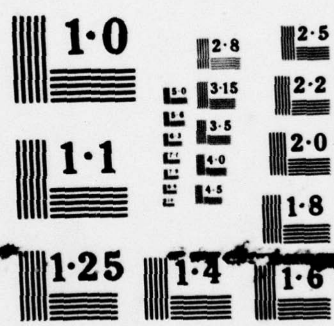

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CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California

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BATHYTHERMOGRAPHIC SURVEYS NEAR NAVAL FACILITIES AT POINT MUGU, CALIFORNIA, AND PEARL HARBOR, HAWAII

May 1979

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The use of naturally cold sea or lake water in place of mechanically chilled water in air conditioning systems was found to be a feasible and energy saving concept for Naval Facilities like those at Point Mugu, CA, and Pearl Harbor, HI. The economic feasibility of this type of air conditioning at these sites depend on the distance and the water depth of the cold water source at the sites. In order to determine these dis- Cont'

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tances and these depths, surveys were conducted which involved (1) assembly of existing data on seawater temperatures and (2) measurement of these temperatures with expendable bathythermographs (XBT). A summary of this existing data and the results of these measurements are given in this report. On the basis of this data and these measurements, estimates were made of the profiles of maximum annual seawater temperature which are also given. It was found that the maximum annual bottom water temperature at the Point Mugu site can be expected in November; it is 10°C (50°F) at a depth of 190 M (620 ft) 1.4 NM offshore. This temperature at the Pearl Harbor site can be above 10°C at a depth of 420 M (1,380 ft) 4.0 NM offshore.

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1.0 INTRODUCTION

The objective of this investigation is to determine the variation of sea water temperature as a function of depth and time in the ocean areas adjacent to the Pacific Missile Test Center at Point Mugu, California (33°30'N to 34°30'N, 118° 30'W to 119°30'W) and Pearl Harbor, Hawaii (20°30'N to 21°30'N, 157°30'W to 158°30'W). This information is required for the design of an air conditioning system that utilizes the natural reservoir of cold sea water for cooling purposes. This system has been proposed as an energy conservation measure but economic feasibility must be demonstrated. The most expensive component of this sea water cooling system is the water intake pipeline that extends offshore from the facility. The cost of the pipeline is a function of the distance offshore and the water depth. Construction and operational costs are optimized by reaching the coldest water (in effect the greatest depth) at the shortest distance from shore.

Contract specifications state that bathythermographic measurements are to be taken along a track for a distance not to exceed the distance to bottom water temperatures of 7.2°C nor four nautical miles from shore, whichever is less. The water temperature is not only a function of horizontal position and depth, but also exhibits seasonal and diurnal variations. Variations attributable to the effects of internal waves and upwelling near the coastline (particularly in Mugu Canyon) may also be measurable. The final product of this investigation is a plot of estimated yearly maximum temperature versus depth and distance from shore along a predetermined trackline. Based on examination of the available historical data, the bathythermographic survey plans for each location were developed.

2.0 POINT MUGU SITE

2.1 Historical Data

The major source of bathythermographic data was NODC (National Oceanographic Data Center) records of mechanical bathythermographs (BT), expendable bathythermographs (XBT) and station data (consisting of continuous salinity-temperature-depth profiles and reversing thermometer measurements) for the area between 33°-35°N and 118°-120°W from 1937 to 1976[7]. Other sources included CCOFI (California Cooperative Oceanic Fisheries Investigations) 1951-52 cruises[11,12], Oceanographic Atlases of the Pacific Ocean[9,10], and discussions with Margaret K. Robinson (an authority on Pacific Ocean bathythermographic analysis[8]. Data for the specific area adjacent to Point Mugu are rare.

Table 1 and Figures 1 and 2 summarize the NODC data, nearly all of which are further offshore than the survey site. At the surface, the mean monthly temperature reaches a maximum of 19.8°C in August but is generally above the annual average from June through November. The maximum observed temperature was 23.7°C on August 18, 1971. Below the surface, the maximum temperature may be delayed by as much as two months. For example, at depths of 300-450 meters the warmest month was September. However, the maximum temperature at these depths was observed on October 22, 1975. Since bottom water temperature near 7.2°C within four nautical miles of Laguna Point is the principal concern of this project, description of historical data will emphasize depths of 200 meters and greater. These depths are easily accessible within the four nautical mile distance limitation. The annual mean temperatures decrease gradually with depth from 8.9°C at 200 meters to 6.9°C at 450 meters. Below 200 meters, the monthly means exhibit minimal seasonal variation and are generally limited to within ±0.4°C of the annual mean. Some of this variability is probably attributable to the large geographical area and diverse sampling instrumentation that have been combined to produce these averages. For this reason, temperature structure at the survey site, and in particular the extreme values, can be expected to differ from these average conditions.

The most representative CCOFI data with respect to the Point Mugu survey area are those stations designated 85.40 (at 33°56'N, 119°09'W) and 87.40 (at 33°40'N, 118°58.5'W). Table 2 summarizes measurements taken during 1951 and 1952 cruises at these two stations. In general, for depths of 200 meters and greater, the annual averages (based on 10 or 11 monthly measurements) are 0.1°C lower than the corresponding averages based on the NODC records. It should be emphasized that the CCOFI data are instantaneous measurements representative of a very small percentage of the time and less useful than continuous or long-period discrete records at a single station for estimation of maximum annual temperature. However, individual monthly measurements do

Table 1

Summary of NODC Bathythermographic Data For the Area Between
33°-35°N and 118°-120°W From 1937-1976

Monthly Mean/Maximum Temperature (°C)	Depth (m) 0	50	100	200	300	350	375	400	425	450
January	14.2/16.2	12.6/15.6	10.3/12.3	9.0/10.4	8.1/9.3	7.7/8.9	7.5/8.7	7.3/8.5	7.1/8.3	6.9/8.1
February	13.9/16.2	12.3/15.6	10.4/12.5	9.0/10.2	8.1/9.2	7.7/8.9	7.4/8.7	7.2/8.5	7.0/8.4	6.9/7.9
March	13.9/17.6	11.9/15.2	10.1/13.0	9.0/10.3	8.1/9.5	7.6/8.9	7.4/8.5	7.2/8.2	7.0/8.0	6.9/7.8
April	14.2/18.9	10.9/13.7	9.7/11.4	8.6/9.7	7.8/9.0	7.3/8.3	7.2/7.9	7.0/7.8	6.9/7.6	6.7/7.4
May	14.8/18.3	10.6/13.2	9.4/10.6	8.6/9.5	7.8/8.3	7.3/7.9	7.1/8.2	6.9/7.6	6.8/7.2	6.6/7.1
June	16.5/19.8	10.6/14.8	9.3/10.7	8.6/9.4	7.8/8.5	7.4/8.3	7.2/8.2	7.0/8.0	6.9/7.8	6.7/7.6
July	18.1/22.9	11.0/16.7	9.7/11.9	8.9/10.5	8.2/9.1	7.9/8.6	7.7/8.4	7.4/8.2	7.2/8.0	7.1/7.8
August	19.8/23.7	12.2/16.8	10.3/12.6	9.0/10.7	8.4/9.5	7.9/9.0	7.7/8.7	7.5/8.7	7.3/8.5	7.1/8.2
September	18.2/20.6	12.4/15.5	9.9/12.1	8.9/10.2	8.4/9.1	8.0/8.7	7.8/8.4	7.6/8.4	7.4/8.1	7.2/8.0
October	17.8/21.4	12.4/17.6	10.3/12.5	9.1/10.2	8.2/9.8	7.8/9.7	7.6/9.4	7.4/9.3	7.2/8.9	6.9/8.6
November	16.2/21.1	11.9/17.7	10.0/12.4	8.9/10.2	8.2/8.8	7.8/8.4	7.6/8.2	7.3/8.0	7.1/7.8	7.0/7.6
December	15.0/17.1	12.2/15.8	10.4/12.4	9.1/10.7	8.2/9.6	7.8/9.1	7.6/8.9	7.3/8.5	7.1/8.3	6.9/8.0
Annual Mean	16.1	11.8	10.0	8.9	8.1	7.7	7.5	7.3	7.1	6.9
Observed Maximum	23.7	17.7	13.0	10.7	9.8	9.7	9.4	9.3	8.9	8.6
Dates of Observed Maximum	8/18/71	11/12/64	3/1/73	8/23/72 12/1/72	10/22/75	10/22/75	10/22/75	10/22/75	10/22/75	10/22/75
Predicted Annual Maximum At Site	-	-	-	9.9	9.1	8.7	8.5	8.3	8.1	7.9

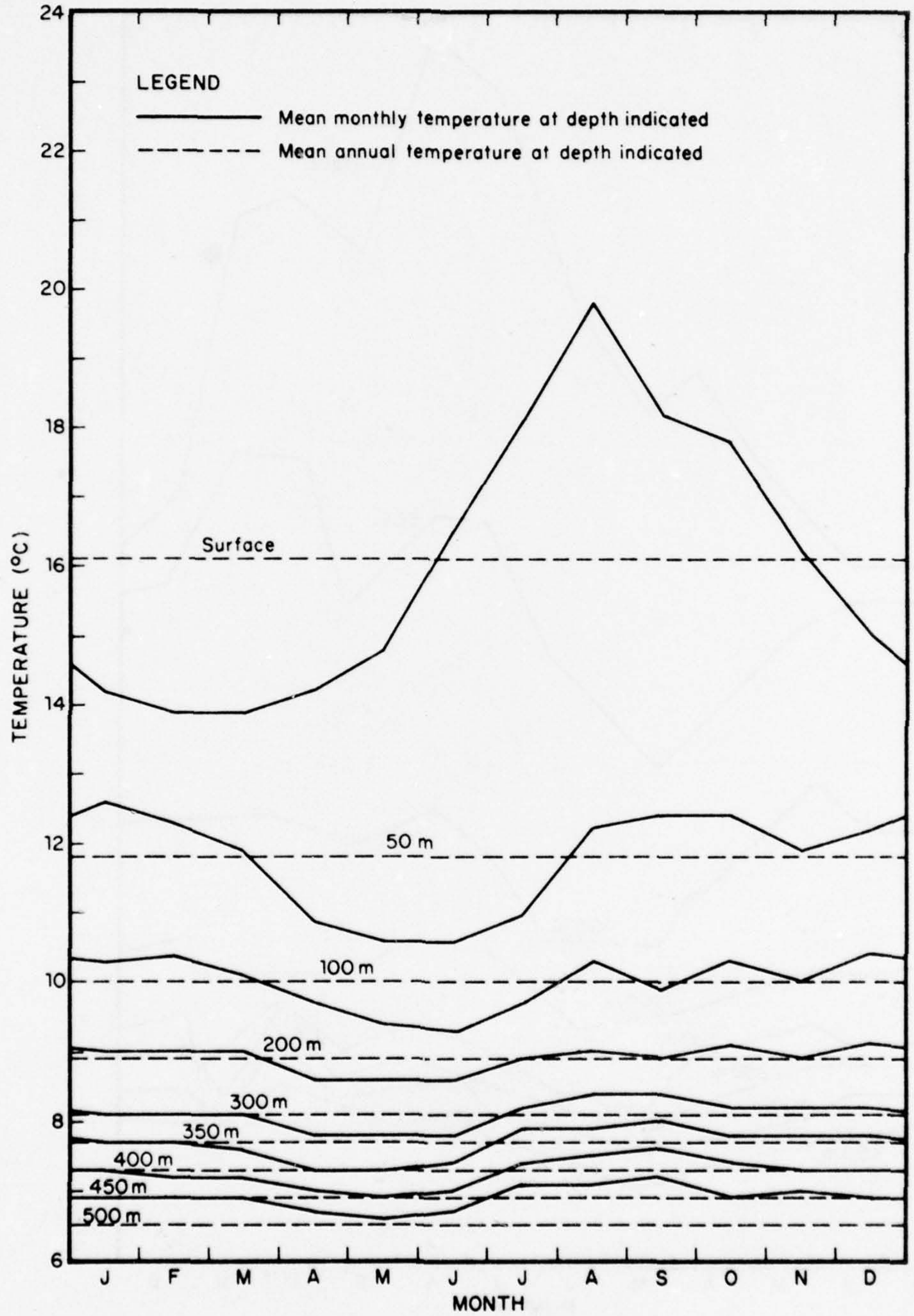


Figure 1.

Mean monthly water temperature for the area between 33°-35°N and 118°-120°W based on NODC data 1937-1976.

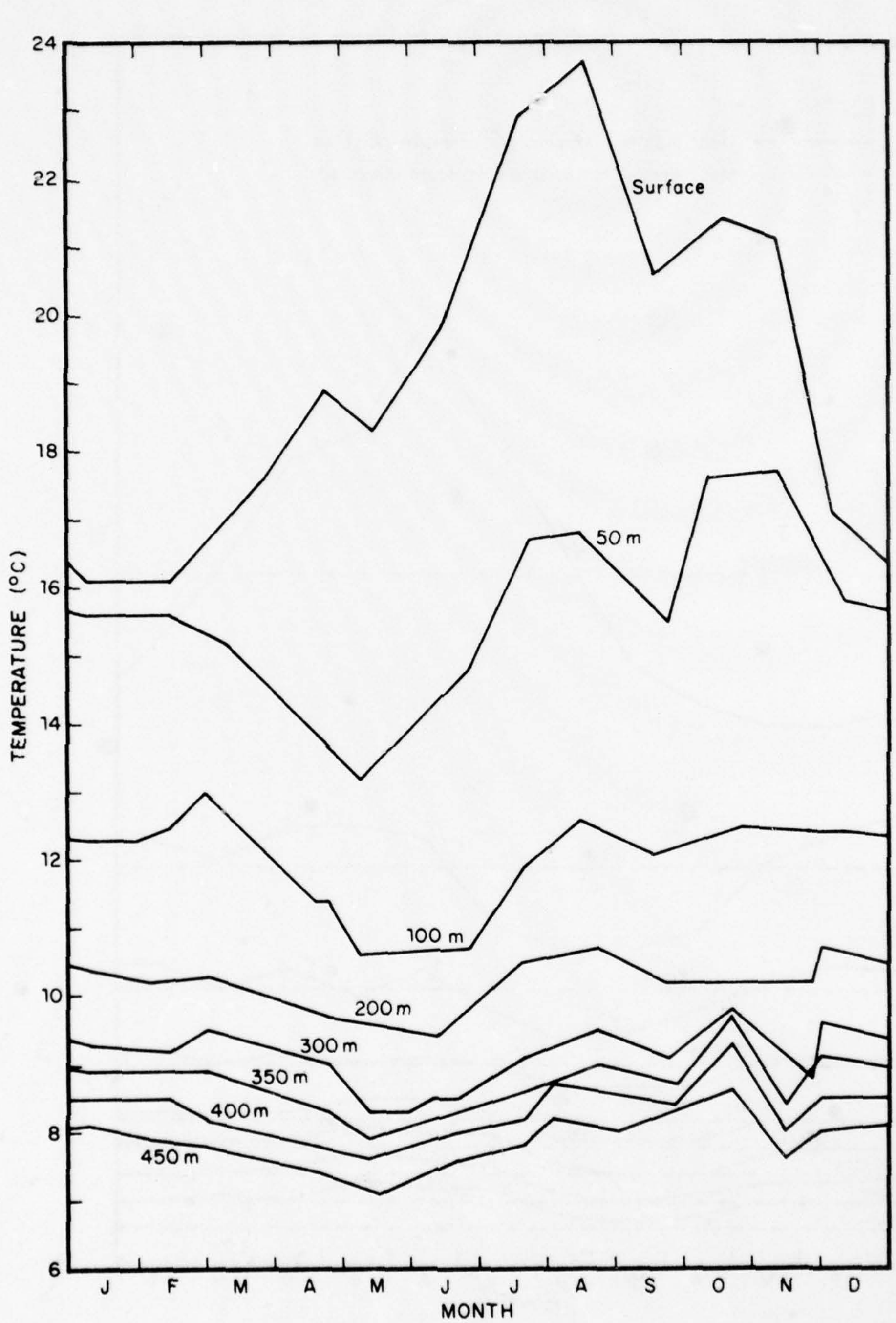


Figure 2.

Maximum monthly water temperature for the area between 33°-35°N and 118°-120°W based on NODC data 1937-1976.

Table 2

Summary of CCOFI Bathythermographic Data Stations 85.40 (33°56'N, 119°09'W) and 87.40(*) (33°40'N, 118°58.5'W) for 1951 and 1952

Monthly Recorded Temperature (°C)	Depth (m) 0	50	100	200	300	350	375	400	425	450
1951										
January*	13.4	10.6	9.7	8.7	7.7	7.4	7.2	7.0	6.8	6.6
February*	13.4	10.6	9.5	8.7	7.6	7.2	7.0	6.7	6.6	6.4
March	13.7	11.0	9.3	8.7	7.8	7.4	7.1	6.9	6.8	6.6
April*	14.5	11.7	9.7	8.4	7.5	7.1	6.9	6.7	6.6	6.5
May*	13.0	9.7	9.0	8.2	7.4	7.1	6.9	6.8	6.7	6.5
June	-	-	-	-	-	-	-	-	-	-
July	-	-	9.4	8.4	7.6	7.5	7.4	7.3	7.2	7.0
August	18.5	12.4	9.9	9.0	8.6	8.1	7.9	7.7	7.5	7.2
September	18.7	11.7	9.8	9.1	8.6	8.0	7.8	7.5	7.2	7.0
October	18.8	12.8	10.6	9.4	8.6	8.0	7.7	7.4	7.2	7.1
November	18.4	12.4	10.2	9.0	8.2	7.8	7.5	7.3	7.1	6.9
December	14.8	13.2	11.0	9.1	8.3	7.8	7.5	7.3	7.1	6.9
Annual Mean	15.7	11.6	9.8	8.8	8.0	7.6	7.4	7.2	7.0	6.8
Annual Maximum	18.8	13.2	11.0	9.4	8.6	8.1	7.9	7.7	7.5	7.2
Date(s) of Annual Maximum	9/27	12/3	12/3	9/27	8/3 9/9 9/27	8/3	8/3	8/3	8/3	8/3
1952										
January	13.9	13.6	10.0	8.6	8.0	7.5	7.2	7.0	6.9	6.7
February	13.1	12.7	10.0	8.6	7.8	7.5	7.3	7.2	7.0	6.8
March	12.9	12.0	9.9	8.9	7.9	7.5	7.4	7.2	7.1	6.9
April*	14.3	10.6	9.2	8.4	7.7	7.3	7.1	6.9	6.8	6.6
May*	15.7	9.9	9.0	8.2	7.4	7.0	6.8	6.6	6.5	6.3
June*	17.0	10.3	9.0	8.2	7.5	7.2	7.0	6.8	6.6	6.4
July	13.0	9.5	9.3	8.7	8.5	7.9	7.6	7.3	7.1	6.9
August	17.7	10.2	9.3	9.0	8.4	8.1	7.9	7.7	7.5	7.2
September	18.1	11.8	9.6	8.9	8.4	8.0	7.8	7.6	7.4	7.2
October	16.0	11.0	9.8	-	-	-	-	-	-	-
November	16.6	12.0	9.9	9.2	8.2	7.8	7.7	7.5	7.3	7.0
December	-	-	-	-	-	-	-	-	-	-
Annual Mean	15.3	11.2	9.6	8.7	8.0	7.6	7.4	7.2	7.0	6.8
Annual Maximum	18.1	13.6	10.0	9.2	8.5	8.1	7.9	7.7	7.5	7.2
Date(s) of Annual Maximum	9/8	1/26	1/26 2/20	11/12	7/12	8/11	8/11	8/11	8/11	8/11 9/8

indicate that temperatures are above the annual average from July-August through December and suggest that the maximum may be expected in this period. These monthly measurements varied within ±0.5°C of the NODC monthly means. Recalling that the monthly means are within ±0.4°C of the annual means, the annual maximum may be of the order of 1°C above the annual mean. The predicted annual maxima are given in Table 1 but the exact date and time of their occurrence is indeterminate from the existing data. The best estimate is approximately the date of the observed maximum temperature.

Oceanographic Atlases confirm the NODC annual means to within ±0.1°C for depths of 200-450 meters but imply that these temperatures are constant year-round. The following discussion evaluates the effects of some of the possible sources of temperature variation within the water column. Diurnal (daily) variation of the water temperature due to absorption of incident solar energy can be as much as 2-3°C. Temperature change of this magnitude occurs only to a depth of a few meters. The magnitude of diurnal variation decreases rapidly as depth increases and should not be detectable as deep as 200 meters considering XBT sensitivity[8]. Appreciable seasonal variation (as much as 5-10°C) is generally limited to the uppermost 100 meters and coastal areas, but may still be measurable at 450 meters[2,6]. When divergent surface flow (offshore) due to winds and currents produces upwelling of cold water from 200-300 meters to the surface, the thermal structure of the upper 100 meters is significantly altered. However, the deeper water remains relatively unchanged. Internal waves can be generated at the boundary between fluids of different density causing periodic vertical displacement of the isotherms. In the ocean, the strongest density gradient occurs at the thermocline but internal waves can exist throughout the water column where vertically-stratified conditions prevail. Internal waves have been observed with periods of approximately 6, 8, 12 and 24 hours and amplitudes of up to 5 meters[1]. In deep water (greater than 200 meters), this may contribute an additional variation of the order of ±0.1°C about the mean. Replication of temperature measurements at a particular station at an hourly or monthly interval is also subject to variations due to horizontal errors in positioning, instrument uncertainty in temperature and depth and water mass advection due to local current anomalies. Other than instrument uncertainty, the magnitudes of these errors are difficult to estimate and may be significant, particularly in the Mugu Canyon area.

2.2 Survey Plan

Based on examination of the historical data, the estimated date of occurrence of the maximum annual bottom temperature for depths between 300 and 450 meters is approximately the middle of October. Three XBT temperature surveys were conducted on September 15, October 12 and November 16, 1978, approximately one month before, on the day of, and one month after the expected maximum bottom water temperature. Each survey consisted of deployment of a series of XBT's at 13 equally-spaced stations along a 160° True trackline extending from Laguna Point (34°05'45"N, 119°06'15"W) to a distance of 3.5 nautical miles from shore. The 160° True trackline was

selected because it provides access to the deepest water at the shortest distance from shore by intersecting the axis of Mugu Canyon. Pipeline construction in the canyon area may require additional engineering considerations.

The survey consisted of a single XBT deployment at each of the 13 stations and replicate observations at a selected station for several hours. The purpose of these repeated observations was to estimate the magnitude of the temperature variability over a short period of time (up to seven hours). In conjunction with the XBT deployments, surface meteorological observations were recorded. These consisted of measurement of sea surface temperature with a bucket thermometer, wet and dry bulb temperature with a sling psychrometer, wind speed and direction with a hand-held anemometer, sea state, percent cloud cover and present weather. These were supplemented with weather observations recorded by the Weather Center Branch of the Geophysics Division of the Pacific Missile Test Center at Point Mugu.

Figure 3 indicates the positions of the 13 stations along the trackline and the charted bathymetry from which the bottom profile in Figure 4 was drawn. Comparison of recent editions of published hydrographic charts revealed a considerable discrepancy in the depth at the stations between approximately two and four nautical miles from shore. The bottom profile (Figure 5) which was drawn from NOAA-NOS (National Oceanic and Atmospheric Administration-National Ocean Survey) Chart Number 18720 (1978) indicates depths of 70-160 meters less than the corresponding stations on Figure 4 which was based on NOAA-NOS Chart Number 18740 (1977). Much of this difference may be due to the use of a 100-fathom contour interval on the 18720 chart and a 50-fathom contour interval on the 18740 chart and the resulting interpolation errors. The problem is compounded by small horizontal displacement of the contours relative to the station locations which can produce large depth errors in the steep canyon area. The depth at each station was checked with a fathometer during the third Point Mugu survey and is indicated on Figure 4. For the most part, these depths were greater than had been expected. Table 3 gives the position and estimated and measured depths of the 13 assigned stations. The depths at Stations 8-13 exceed the rated limit of the T-4 type XBT probe of 460 meters (1500 feet). However, the bottom temperature at these stations may be estimated by extrapolation of the NODC data. The mean annual temperature decreases by approximately 0.2°C/25m between 200 and 450 meters.

2.3 Instrumentation

The expendable bathythermograph system (XBT) manufactured by the Sippican Corporation (Marion, Mass.) produces a continuous temperature versus depth trace from the surface to a depth of 460 meters. The system on loan from the Pacific Missile Test Center for the project consisted of a deck-mounted launcher (Model Number LM-2, Serial Number 20819), XBT recorder (Model Number MK2A-1, Serial Number 748026) and XBT probes (Model T-4). The temperature is sensed by a thermistor in the nose of the probe and the depth is determined as a function of time assuming a constant probe descent rate.

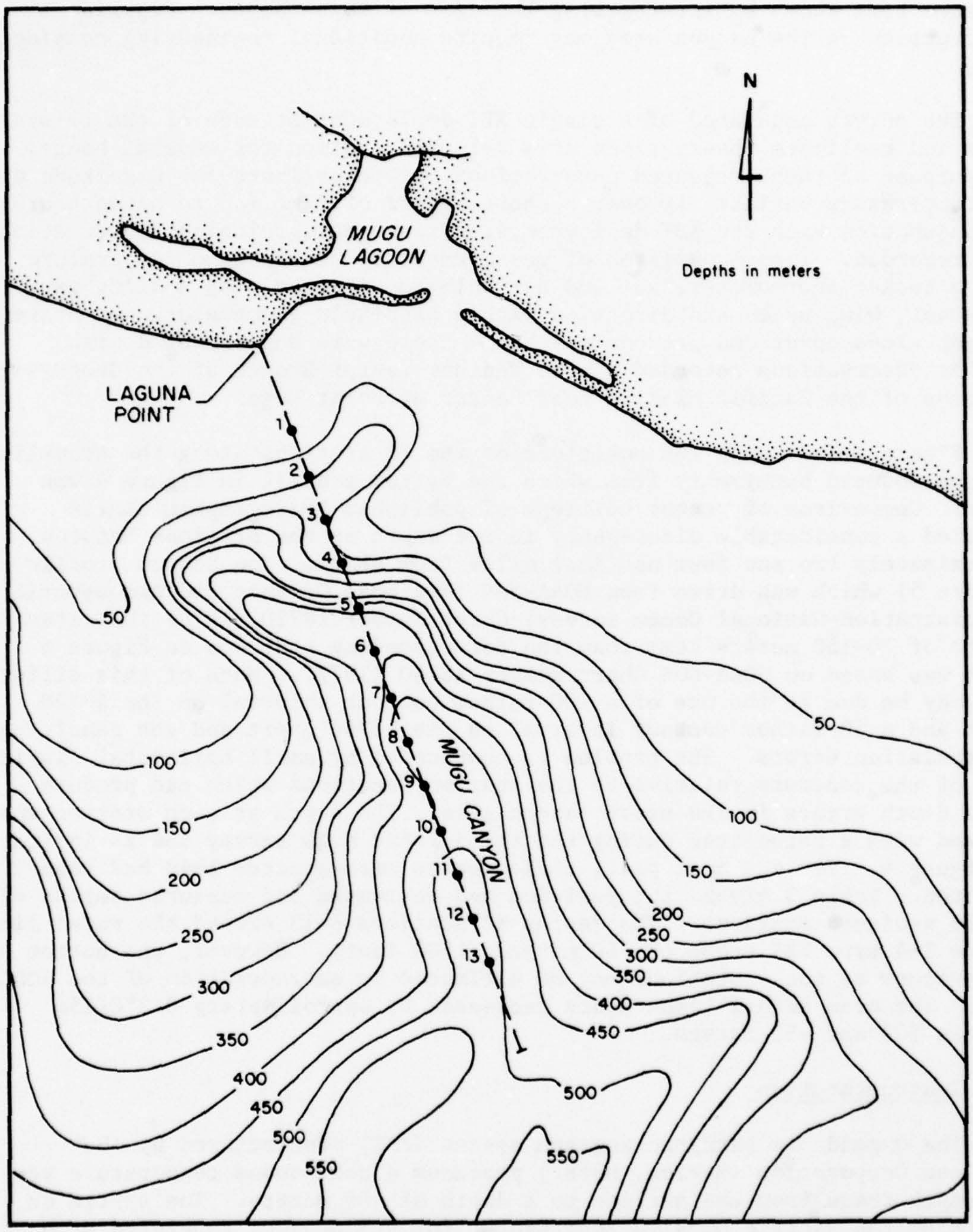


Figure 3.

Location of XBT deployments for Point Mugu surveys September 15, October 12 and November 16, 1978 and existing bathymetry based on NOAA-NOS Chart 18740 (1977).

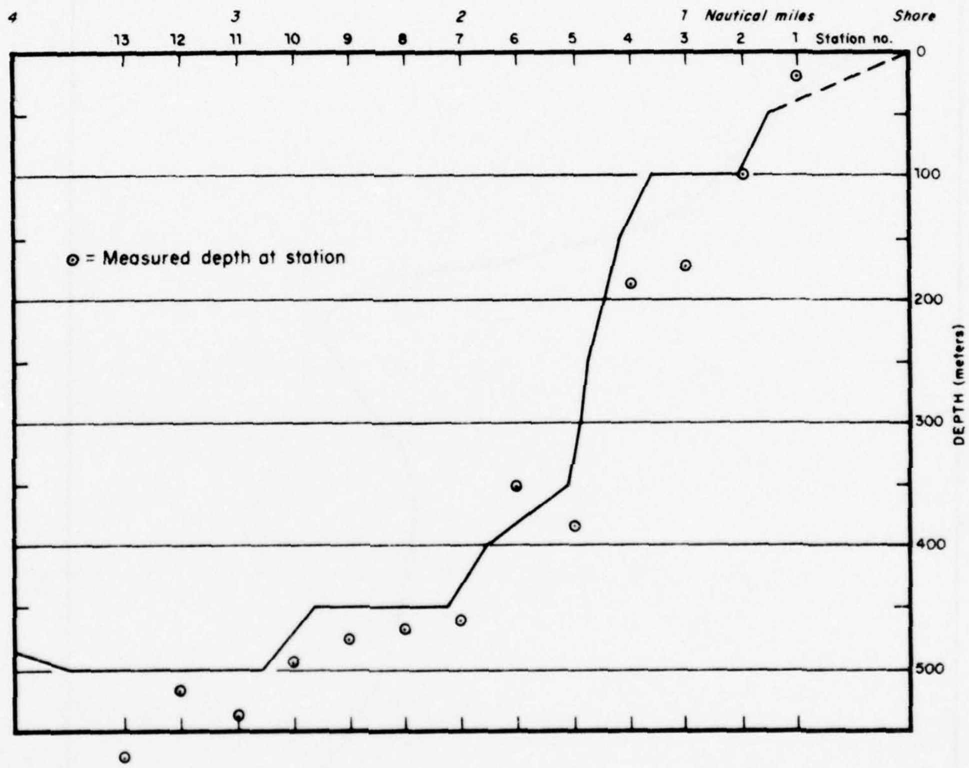


Figure 4.

Seafloor profile along XBT survey trackline as determined from NOAA-NOS Chart 18740 (1977) and fathometer-measured depths.

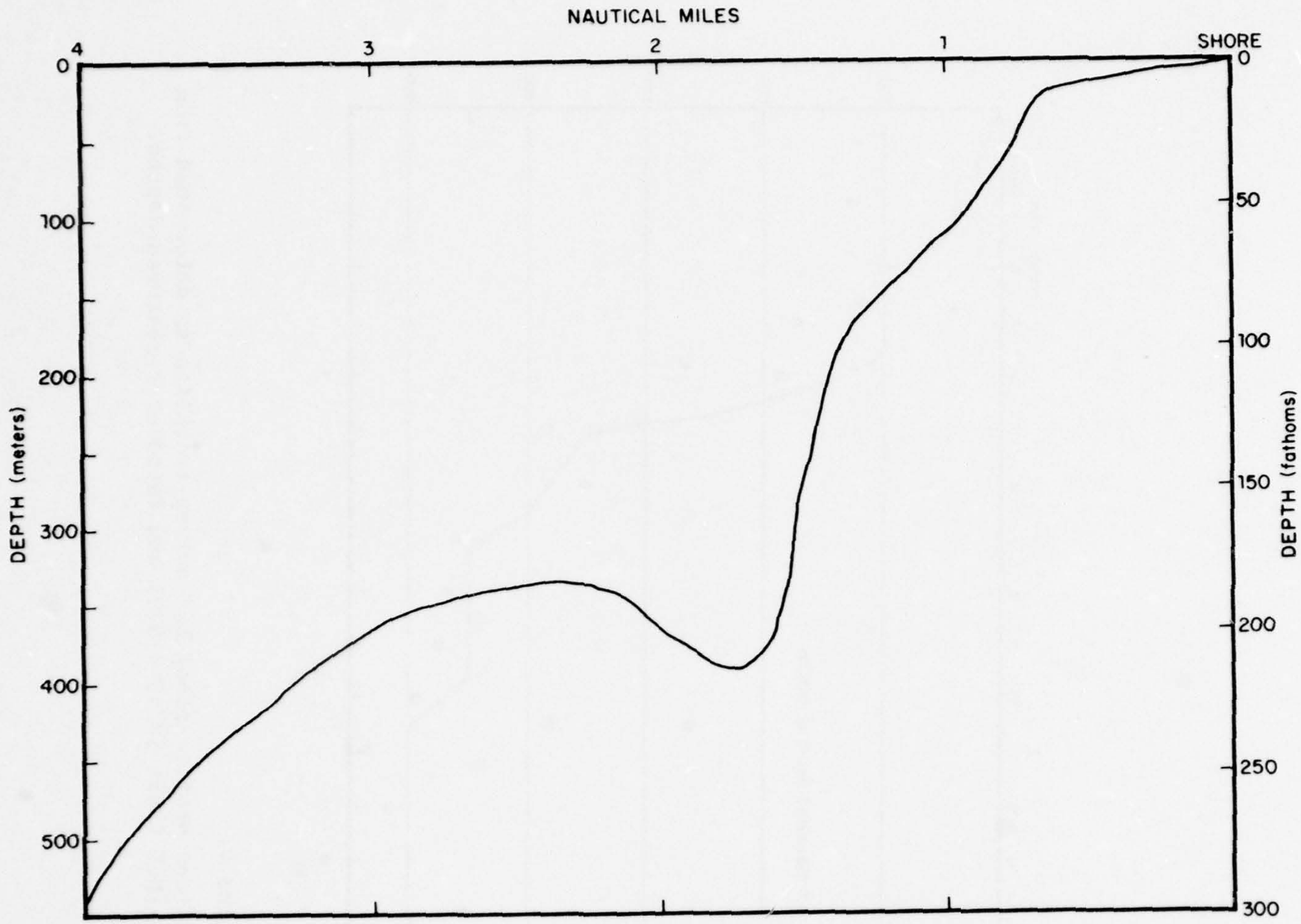


Figure 5.

Seafloor profile along XBT survey trackline as determined from NOAA-NOS Chart 18720 (1978).

Table 3

Point Mugu XBT Survey Station Locations,
Depths and Expected Bottom Temperatures Based on Historical Data

Station Number	Distance Along 160°T Trackline (N.M.)	Latitude	Longitude	Chart Depth (m) NOAA-NOS Chart 18720 21st Ed. 1978	Chart Depth (m) NOAA-NOS Chart 18740 23rd Ed. 1977	Measured Depth (m)	Bottom Temperatures (°C) Annual Mean	Bottom Temperatures (°C) Estimated Annual Maximum
1	0.50	34°05'15"N	119°06'03"W	14	18	20	14.4	-
2	0.75	34°05'02"	119°05'57"	46	90	101	10.0	-
3	1.00	34°04'48"	119°05'51"	110	120	174	9.2	10.2
4	1.25	34°04'33"	119°05'45"	160	130	188	9.0	10.0
5	1.50	34°04'19"	119°05'39"	274	320	383	7.4	8.4
6	1.75	34°04'05"	119°05'32"	389	380	353	7.7	8.7
7	2.00	34°03'52"	119°05'25"	361	430	460	6.8	7.8
8	2.25	34°03'37"	119°05'20"	334	470	468	6.8	7.8
9	2.50	34°03'23"	119°05'13"	338	450	476	6.7	7.7
10	2.75	34°03'09"	119°05'07"	347	470	492	6.6	7.6
11	3.00	34°02'55"	119°05'01"	361	510	538	6.2	7.2
12	3.25	34°02'41"	119°04'54"	393	510	518	6.4	7.4
13	3.50	34°02'26"	119°04'48"	430	510	571	5.9	6.9

The rated system temperature accuracy is ±0.2°C and the depth accuracy is ±2% or ±4.6m whichever is greater. System reliability is generally good. Minor problems that did occur included chart drive slippage and temperature calibration drift of up to 0.2°C. The manual available from Sippican provides additional information on system operation and maintenance.

As a check of proper XBT operation, the sea surface temperature was measured with a bucket thermometer. The thermometer was supplied by Kahl Scientific (El Cajon, Calif.). The temperature can be read to the nearest 0.1°C. The calibration correction is approximately +0.1°C between 15°C and 30°C.

The wet and dry bulb temperatures were measured with a sling psychrometer manufactured by Weksler Instruments Corporation (Freeport, New York). The temperatures were read to the nearest whole 1°F, and estimated to the nearest 0.1°F. Percent relative humidity was computed using the psychrometric slide rule provided by Weksler. Instrument temperature accuracy is approximately ±1°F resulting in a ±5% relative humidity accuracy.

The wind speed and direction were measured with a hand-held anemometer manufactured by the Belfort Instrument Company (Baltimore, Maryland). The instrument is Catalog Number 6052 and Serial Number 678. The rated speed accuracy is 3% of full scale (0.45 knots on the 0-15 knot scale and 1.8 knots on 0-60 knot scale), and the threshold speed is 1.0 knot. The rated direction accuracy is ±2°. Wind measurements were taken approximately 10 feet above sea level.

The water depth was determined by a Raytheon Model 731 (Serial Number 879181) fathometer whose rated accuracy is ±1%. The transducer was suspended one meter below the surface and the record was read to the nearest fathom, then converted to meters.

Station positioning was accomplished using a Motorola Mini-Ranger positioning system which consisted of two shore-based reference stations, a shipboard receiver-transmitter and range console. The shore stations were located at the Hueneme Light (34°08'43"N, 119°12'31"W) and Springville (34" 13'42"N, 119°05'44"W). Simultaneous ranges from these two fixed stations determine the location of the ship. The rated range error is ±3m. This greatly exceeds the positioning accuracy of 61 meters specified in the contract. Visual positioning by horizontal sextant angles is an alternative that can also meet this accuracy under ideal conditions, but is severely hampered by rough seas and low visibility. The high incidence of fog off Point Mugu from June-November[2] resulted in selection of the Mini-Ranger system.

2.4 Presentation of Data and Discussion of Results

Copies of the XBT traces of the three Point Mugu surveys are given in Figures 6, 7 and 8. Each is identified by station number, date and time. Measured sea surface temperature is also included. All XBT's were well

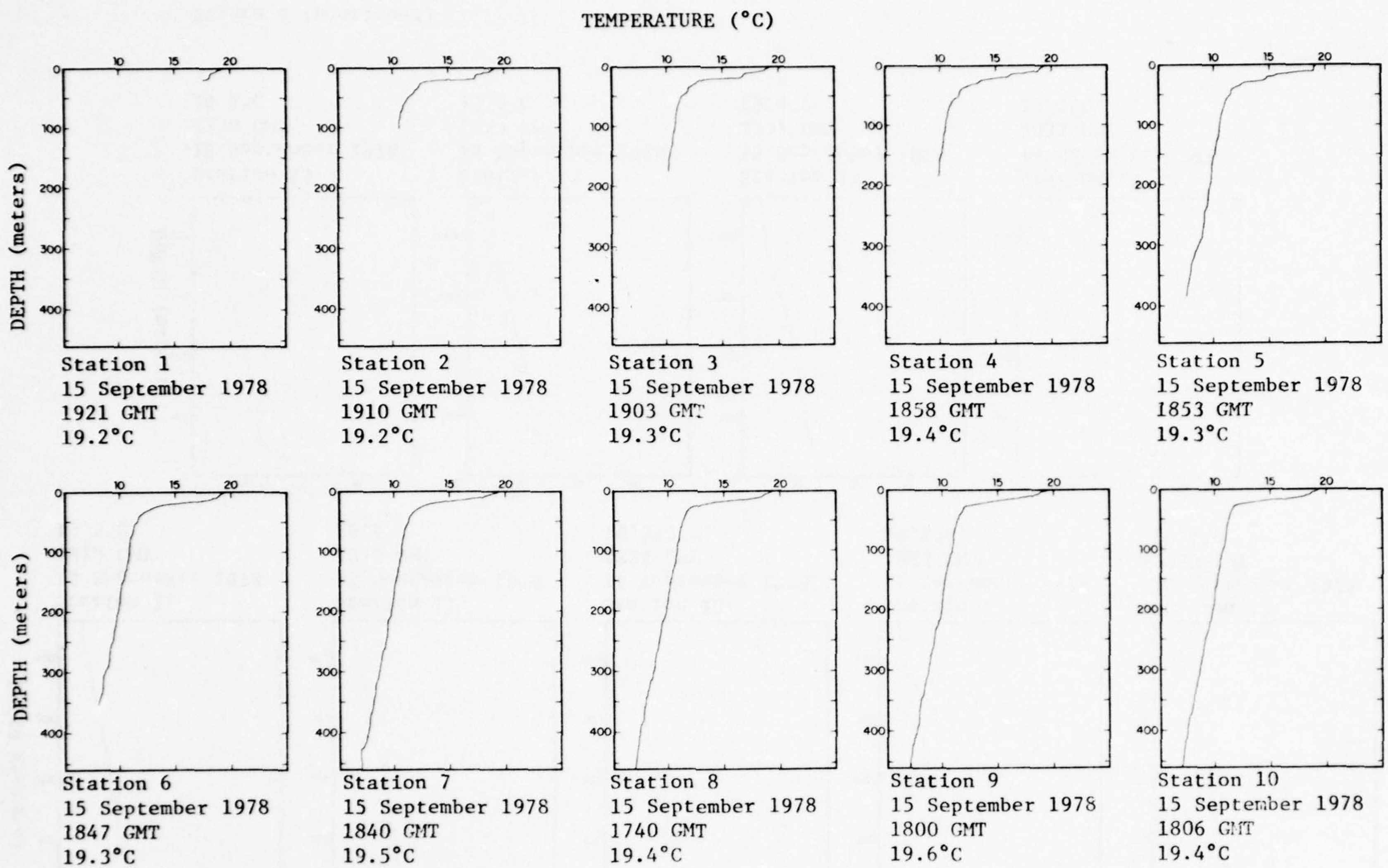


Figure 6. XBT traces of September 15-16, 1978 survey at Point Mugu, California and observed bucket thermometer sea surface temperatures.

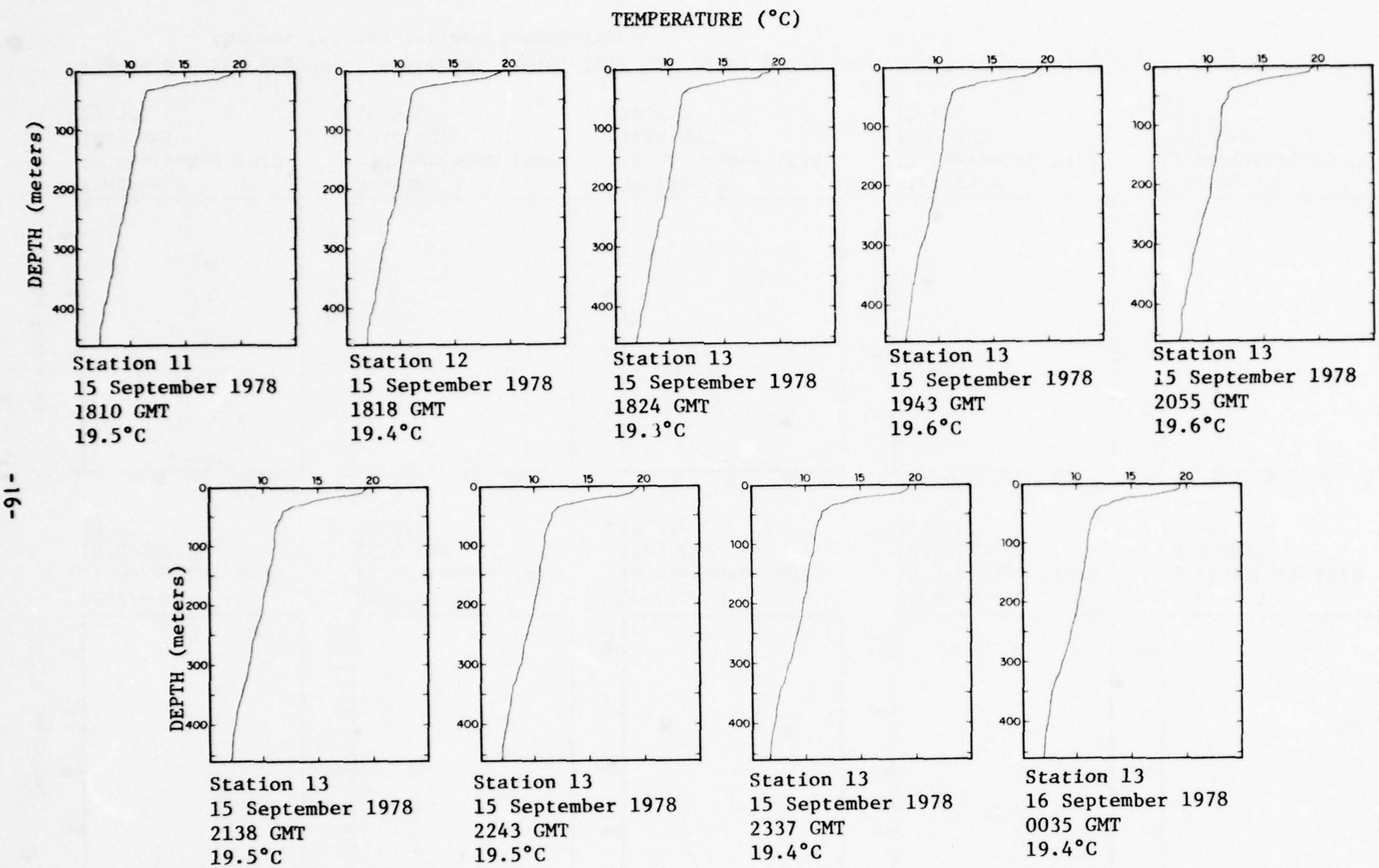


Figure 6 (continued)

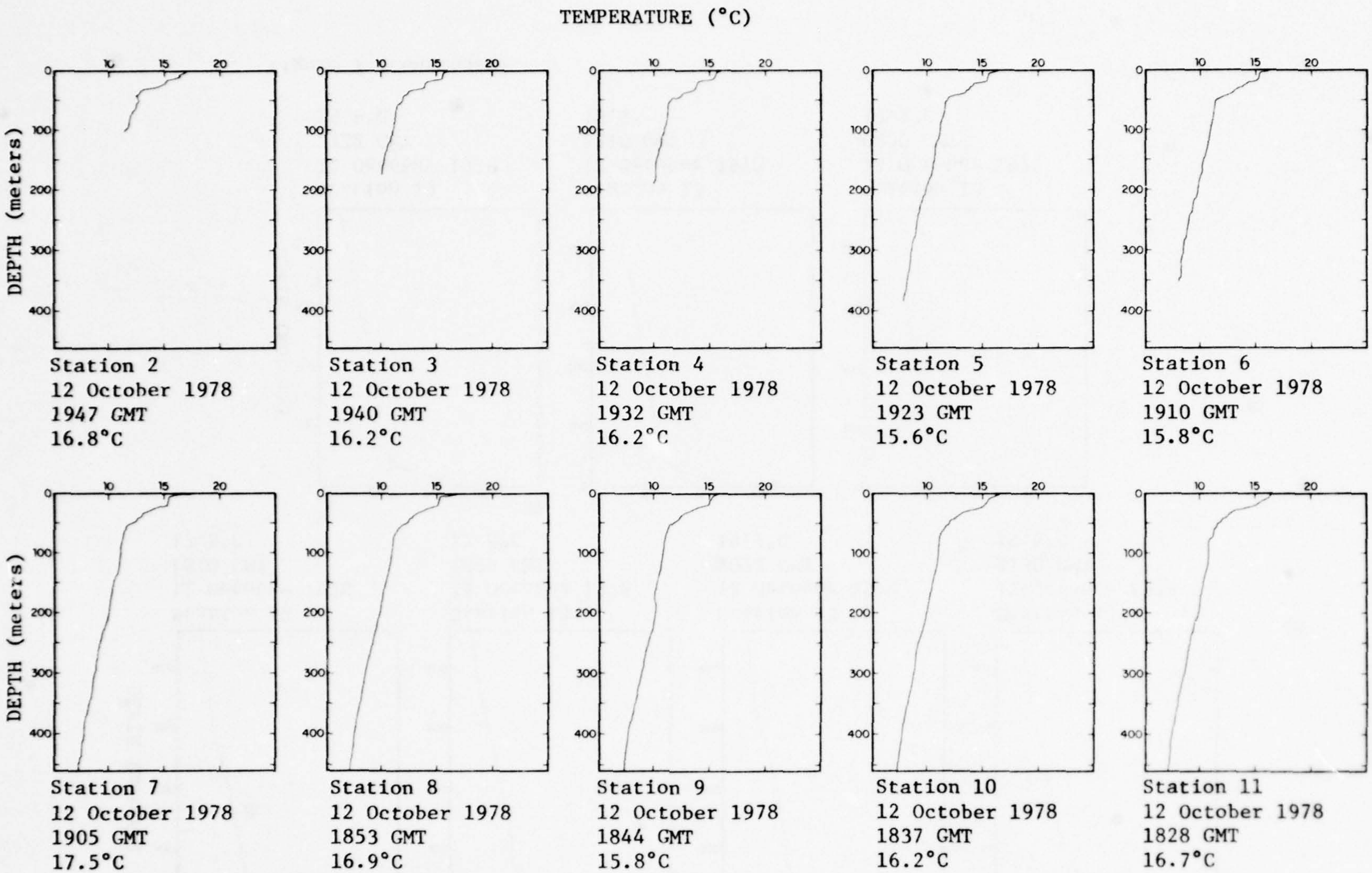
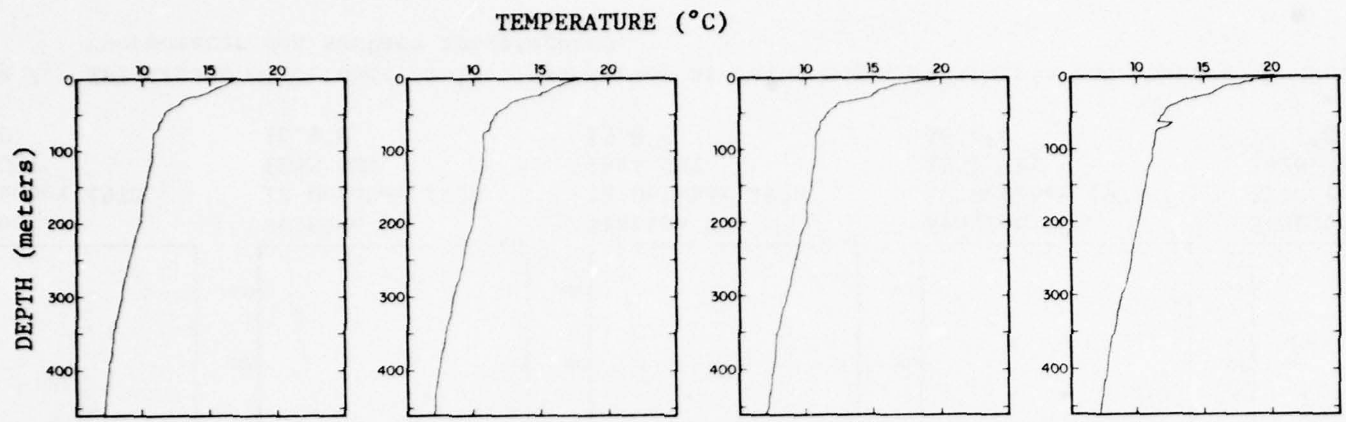


Figure 7. XBT traces of October 12-13, 1978 survey at Point Mugu, California and observed bucket thermometer sea surface temperatures.

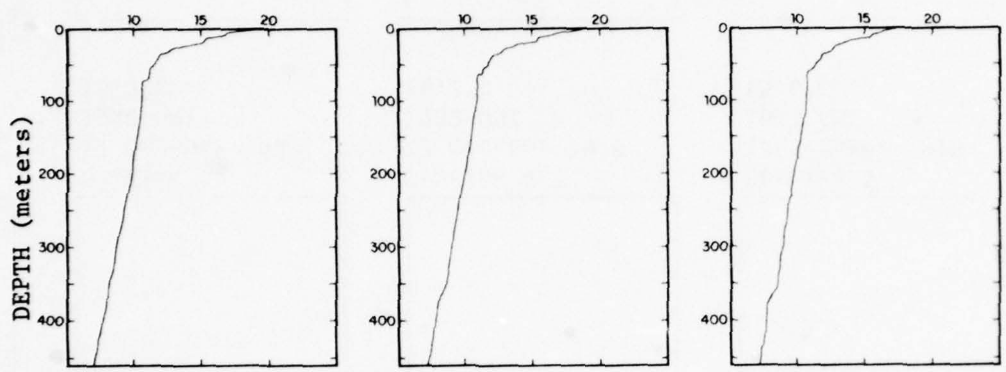


Station 12
12 October 1978
1810 GMT
17.5°C

Station 13
12 October 1978
1800 GMT
17.8°C

Station 13
12 October 1978
2022 GMT
19.7°C

Station 13
12 October 1978
2130 GMT
19.6°C



Station 13
12 October 1978
2222 GMT
19.8°C

Station 13
12 October 1978
2310 GMT
18.6°C

Station 13
13 October 1978
0000 GMT
17.2°C

Figure 7 (continued)

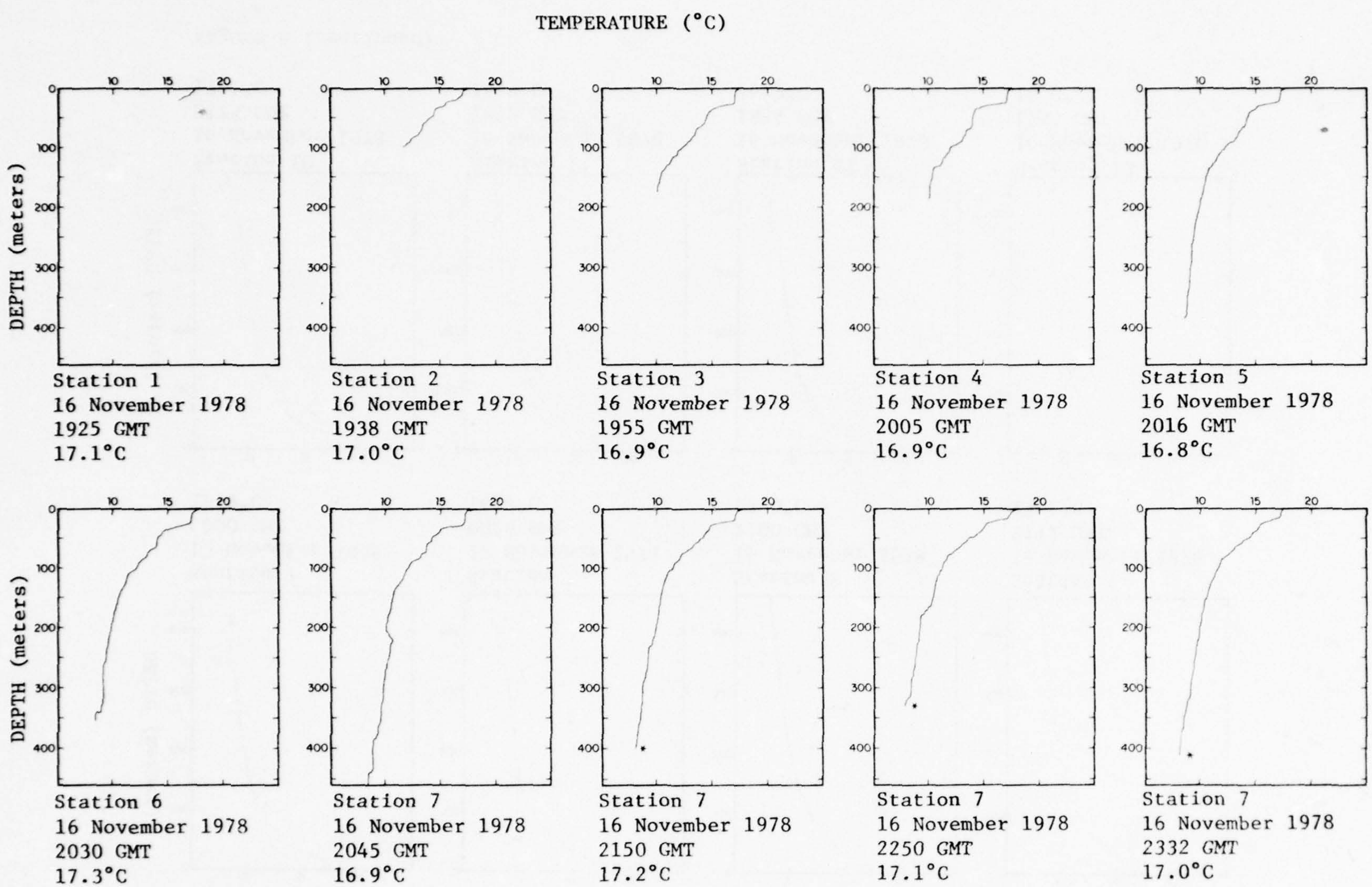


Figure 8. XBT traces of November 16-17, 1978 survey at Point Mugu, California, California and observed bucket thermometer sea surface temperatures.
(*see text)

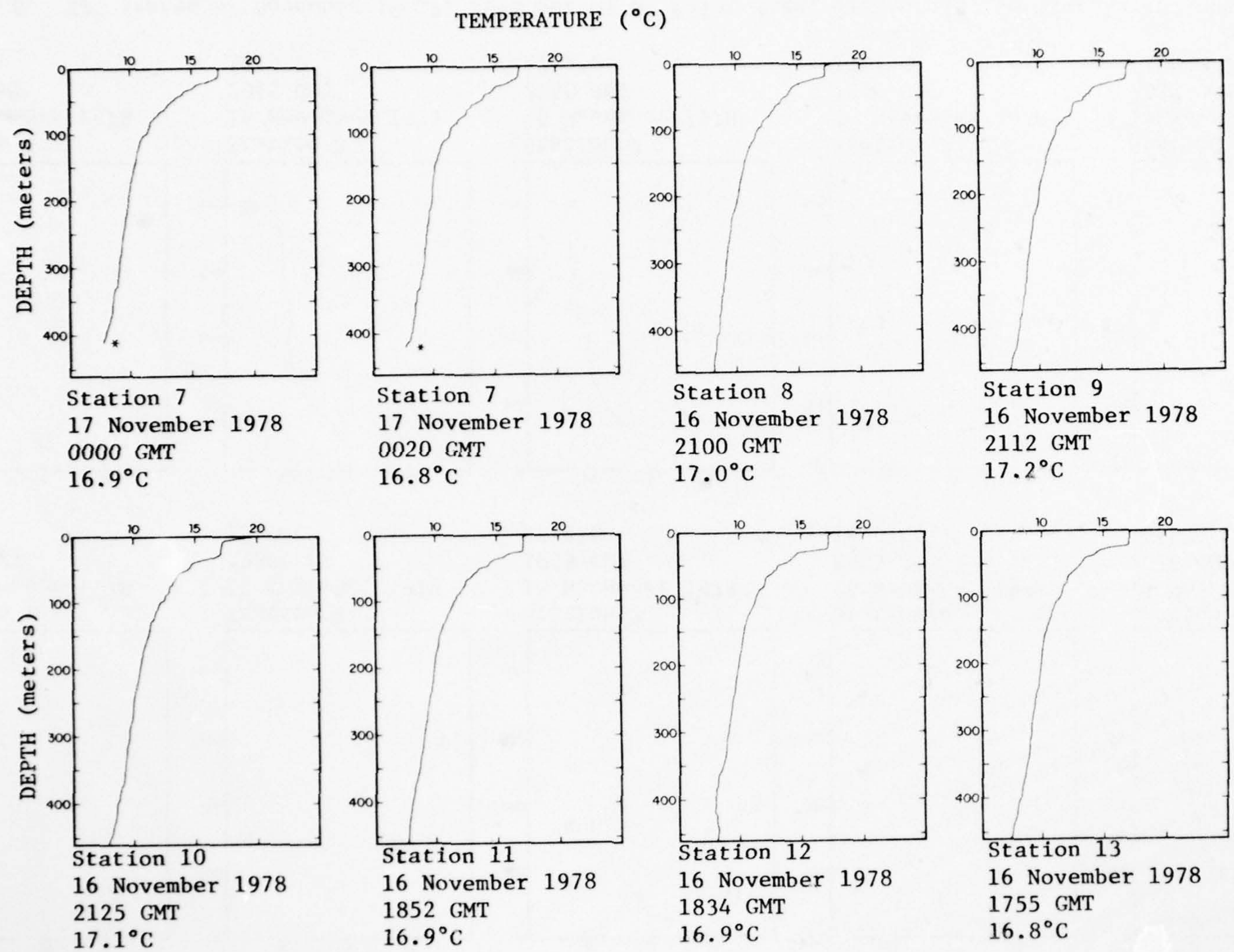


Figure 8 (continued)

within 61 meters of the assigned stations in Figure 3, and most often within 10 meters. In some of the original traces of Stations 1-6, the depth of the water column was clearly indicated by a horizontal trace (increase or decrease in temperature at a constant depth) followed by a nearly vertical trace (little change in temperature as depth apparently increases). However, when this was not a dependable method of depth determination, the traces were truncated at the measured bottom depth. For Stations 7-13 no bottom was visible as the water depth exceeds the T-4 XBT range of 460 meters. During the November survey, slippage of the chart drive mechanism resulted in incorrect traces with respect to the depth coordinate. This occurred repeatedly at Station 7 and resulted in an apparent depth much less than the measured depth of 460 meters. The surface and bottom temperatures were assumed to be correct and intermediate values approximated based on careful examination of the records and comparison with nearby stations. The surface and bottom temperatures and the depths of the 17.5, 15.0, 12.5, 10.0, 9.5, 9.0, 8.5, 8.0, 7.5 and 7.0°C isotherms of all the XBT's are summarized in Table 4. Estimates for depths greater than 460 meters are based on linear extrapolation of the slope between 350 meters and 460 meters. Shipboard weather observations are summarized in Tables 5, 6 and 7 and supplemented with observations recorded by the Weather Center Branch of the Geophysics Division of the Pacific Missile Test Center at Point Mugu.

Figure 9 was constructed by plotting the maximum depth of each isotherm at each station and joining these points. The maximum recorded bottom temperatures are also indicated. At depths of 200 meters and greater, these maxima were recorded during the November 16 survey and constitute the best available estimates of the maximum annual sea water temperatures as a function of depth and distance offshore. Although the annual maximum bottom temperatures were anticipated in October, September and November are also likely months based on the results of this survey. Repeated XBT deployments at Station 7 in November indicated that bottom temperatures varied between 7.7 and 8.2°C in a four-hour period. Similarly, repeated observations of Station 13 showed temperatures at 460 meters that varied between 6.7 and 7.2°C in September and 7.0 and 7.2°C in October within a six-hour period. Variability of this magnitude (due to environmental changes and instrument uncertainty) can be expected at Stations 7-13. It is conceivable that dependence on a single XBT deployment at each station may have resulted in underestimation of the maximum water temperatures by as much as 0.5°C. An alternative method of displaying the XBT data is to construct a composite maximum temperature versus depth profile representative of all the stations by assembling the greatest measured depth of each isotherm into a single curve (Figure 9 insert). This curve estimates maximum annual bottom temperatures for Stations 5-13 that are 0 to 0.2°C higher than the estimates based on historical data in Table 3.

2.5 Conclusions

To summarize, the surveys showed that the observed maximum bottom temperature at 460 meters (Station 7) of 8.2°C occurred in November. This was 1.4°C above the expected annual mean of 6.8°C and 0.4°C above the predicted annual maximum of 7.8°C (Table 3). At this depth, the monthly mean temperatures are expected to vary between 6.6°C in May and 7.2°C in September. Maxima of

Table 4

Summary of Monthly XBT Survey Data: Surface Temperature, Bottom Temperature and Depth of Selected Isotherms (* indicates estimated)

		Station Number												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Surface Temperature (°C)														
	September	19.2	19.2	19.3	19.4	19.3	19.3	19.5	19.4	19.6	19.4	19.5	19.4	19.3
	October	-	17.2	16.5	16.0	17.0	17.0	16.5	16.5	16.5	16.5	17.3	17.5	18.0
	November	17.4	17.5	17.5	17.6	17.7	17.6	18.0	17.7	18.0	17.6	17.2	17.2	17.2
Depth of Isotherm (m)														
17.5°C	September	19	11	11	13	13	15	12	12	13	14	14	13	16
	October	-	-	-	-	-	-	-	-	-	-	-	0	3
	November	-	0	0	2	2	1	2	1	2	3	0	-	-
15.0°C	September	-	20	20	21	20	20	16	17	18	17	19	19	21
	October	-	22	16	16	20	19	18	16	18	18	20	18	20
	November	-	33	36	32	36	34	35	32	38	40	36	29	28
12.5°C	September	-	27	30	33	33	32	26	25	26	23	29	28	31
	October	-	41	38	42	43	42	42	36	36	36	38	37	39
	November	-	85	98	97	95	88	90	84	83	97	68	64	63
10.0°C	September	-	-	-	165	158	190	173	183	190	180	180	180	190
	October	-	-	-	192	200	180	199	183	220	190	190	180	200
	November	-	-	-	-	190	192	-	213	220	230	198	192	200
9.5°C	September	-	-	-	-	229	245	217	221	228	226	233	232	240
	October	-	-	-	-	224	217	225	220	250	224	223	220	230
	November	-	-	-	-	233	245	-	267	250	250	253	254	255
9.0°C	September	-	-	-	-	280	290	259	272	272	260	268	255	272
	October	-	-	-	-	273	250	267	260	295	255	253	255	272
	November	-	-	-	-	320	340	-	340	320	310	308	303	320
8.5°C	September	-	-	-	-	307	328	315	315	314	313	310	300	311
	October	-	-	-	-	327	290	317	295	330	324	303	300	300
	November	-	-	-	-	-	-	-	405	381	370	360	353	375
8.0°C	September	-	-	-	-	330	-	362	345	355	365	365	358	358
	October	-	-	-	-	372	-	363	343	375	360	347	337	350
	November	-	-	-	-	-	-	-	463	430	420	415	390	417

Table 4 (continued)

	Station Number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Depth of Isotherm (m) (continued)													
7.5°C September	-	-	-	-	380	-	411	390	408	403	405	401	404
October	-	-	-	-	-	-	432	400	425	420	398	390	400
November	-	-	-	-	-	-	-	-	470*	470*	470*	-	455
7.0°C September	-	-	-	-	-	-	430	460	476*	460	480*	445	457
October	-	-	-	-	-	-	-	460	-	-	490*	468*	470*
November	-	-	-	-	-	-	-	-	-	-	-	-	550*
Bottom Temperature (°C)													
September	17.5	10.6	10.2	9.9	7.4	8.1	6.9	7.0*	7.0*	6.7*	6.7*	6.5*	6.0*
October	-	11.5	10.2	10.0	8.0	8.2	7.2	7.0*	7.2*	7.1*	6.8*	6.8*	6.5*
November	16.0	11.6	10.1	10.1	8.7	9.0	-	8.0	7.3*	7.3*	7.1*	7.2*	6.8*

Table 4 (continued)

		Station Number												
		7	7	7	7	7	13	13	13	13	13	13		
Surface Temperature (°C)														
September		-	-	-	-	-	19.6	19.6	19.5	19.5	19.4	19.3		
October		-	-	-	-	-	20.0	20.5	20.0	20.0	17.5	-		
November		17.5	17.7	17.5	17.2	17.1	-	-	-	-	-	-		
Depth of Isotherm (m)														
17.5°C	September	-	-	-	-	-	16	17	13	17	17	18		
	October	-	-	-	-	-	7	10	4	5	0	-		
	November	0	5	0	-	-	-	-	-	-	-	-		
15.0°C	September	-	-	-	-	-	22	23	20	22	22	23		
	October	-	-	-	-	-	25	27	21	20	15	-		
	November	26	33	39	30	33	-	-	-	-	-	-		
12.5°C	September	-	-	-	-	-	34	37	35	33	33	37		
	October	-	-	-	-	-	35	41	33	35	31	-		
	November	73	70	80	73	75	-	-	-	-	-	-		
10.0°C	September	-	-	-	-	-	180	229	195	198	190	219		
	October	-	-	-	-	-	200	218	190	205	180	-		
	November	200	200	211	200	200	-	-	-	-	-	-		
9.5°C	September	-	-	-	-	-	233	255	233	238	235	250		
	October	-	-	-	-	-	230	263	235	260	233	-		
	November	263	263	267	263	263	-	-	-	-	-	-		
9.0°C	September	-	-	-	-	-	271	288	270	275	268	286		
	October	-	-	-	-	-	270	296	285	307	290	-		
	November	320	325	333	350	350	-	-	-	-	-	-		
8.5°C	September	-	-	-	-	-	298	330	315	311	300	313		
	October	-	-	-	-	-	311	325	323	360	355	-		
	November	400	388	400	400	400	-	-	-	-	-	-		
8.0°C	September	-	-	-	-	-	337	368	356	342	329	335		
	October	-	-	-	-	-	345	372	374	378	370	-		
	November	-	440	-	440	440	-	-	-	-	-	-		
7.5°C	September	-	-	-	-	-	387	420	385	380	360	375		
	October	-	-	-	-	-	417	430	417	440	431	-		
	November	-	-	-	-	-	-	-	-	-	-	-		

Table 4 (continued)

	Station Number												
	7	7	7	7	7	13	13	13	13	13	13		
Depth of Isotherm (m) (continued)													
7.0°C September	-	-	-	-	-	450	492*	470*	440	410	448		
October	-	-	-	-	-	462*	480*	452	478*	490*	-		
November	-	-	-	-	-	-	-	-	-	-	-		
<u>Bottom Temperature (°C)</u>													
September	-	-	-	-	-	6.5*	6.3*	6.5*	6.2*	6.0*	6.0*		
October	-	-	-	-	-	6.0*	6.2*	5.7*	6.1*	6.2*	-		
November	8.2	7.8	8.2	7.8	7.7	-	-	-	-	-	-		

Table 5

Summary of September 15-16, 1978 Surface Meteorological Observations

*indicates Pacific Missile Test Center Observation; ( ) indicates estimated

Time (GMT)	Surface Visibility (Statute Miles)	Weather	Sea Level Pressure (mb)	Air Temperature (°F)	Dew Point (°F)	Wet Bulb Temperature (°F)	Relative Humidity (%)	Wind Dir. (°)	Wind Speed (kts)	Sky Cover (10ths)	Sea Surface Temp. (°C)	Sea State
1757*	9	-	1017.8	70	60	-	71	160	5	0	-	-
1857*	10	-	1017.6	70	60	-	71	250	5	3	-	-
1945	20	-	-	67.5	-	63.5	80	(240)	2	3	19.6	3
1957*	15	-	1017.0	70	60	-	71	240	5	4	-	-
2051	20	-	-	67.8	-	64.0	81	(240)	2.5	4	19.6	3
2057*	15	-	1016.5	71	61	-	71	240	5	3	-	-
2134	20	-	-	67.8	-	64.0	81	270	3.5	3	19.5	3
2157*	15	-	1016.2	71	61	-	71	260	4	4	-	-
2238	-	-	-	67.0	-	64.5	86	240	(5)	2	19.5	3
2257*	10	-	1015.8	70	61	-	73	280	9	4	-	-
2335	-	-	-	66.0	-	64.0	90	(240)	(10)	3	19.4	3
2357*	7	-	1015.2	68	60	-	76	270	10	7	-	-
0057*	7	-	1015.8	64	59	-	84	300	7	10	-	-

Table 6

Summary of October 12-13, 1978 Surface Meteorological Observations

*indicates Pacific Missile Test Center Observation

Time (GMT)	Surface Visibility (Statute Miles)	Weather	Sea Level Pressure (mb)	Air Temperature (°F)	Dew Point (°F)	Wet Bulb Temperature (°F)	Relative Humidity (%)	Wind Dir. (°)	Wind Speed (kts)	Sky Cover (10ths)	Sea Surface Temp. (°C)	Sea State
1757*	5	Haze	1012.2	72	60	-	66	260	4	1	-	-
1857*	5	Haze	1012.1	73	62	-	68	250	4	1	-	-
1957*	5	Haze	1011.6	74	64	-	71	210	5	1	-	-
2057*	5	Haze	1011.0	73	64	-	73	260	5	1	-	-
2157*	5	Haze	1010.2	76	64	-	66	250	7	2	-	-
2257*	5	Haze	1010.1	74	65	-	74	260	6	2	-	-
2357*	5	Haze	1009.7	73	63	-	71	270	8	2	-	-
0057*	7	-	1009.6	70	62	-	76	300	4	3	-	-
1800-0100	Weather conditions at sea relatively unchanged throughout day; visibility 10 miles (except 2000-2200 less than 1 mile in fog), wind speed 1-6 knots, sky cover 2-3 and sea state 2-3.											

Table 7

Summary of November 16-17, 1978 Surface Meteorological Observations

*indicates Pacific Missile Test Center Observation

Time (GMT)	Surface Visibility (Statute Miles)	Weather	Sea Level Pressure (mb)	Air Temperature (°F)	Dew Point (°F)	Wet Bulb Temperature (°F)	Relative Humidity (%)	Wind Dir. (°)	Wind Speed (kts)	Sky Cover (10ths)	Sea Surface Temp. (°C)	Sea State
1755	20	-	-	61.0	-	53.5	61	Var.	2	0	16.8	2
1757*	30	-	1024.0	60	39	-	46	080	1	0	-	-
1857*	30	-	1023.9	64	39	-	40	220	2	0	-	-
1957*	15	-	1023.3	65	42	-	43	250	3	0	-	-
2057*	15	-	1022.5	65	42	-	43	260	5	0	-	-
2157*	10	-	1022.0	64	45	-	50	280	5	0	-	-
2200	20	-	-	62.5	-	55.5	64	270	5	0	17.2	2
2257*	10	-	1021.5	64	47	-	54	280	5	0	-	-
2300	20	-	-	-	-	-	-	-	-	0	17.1	2
2335	20	-	-	610	-	57.5	80	270	6	0	17.0	2
2357*	10	-	1021.4	62	47	-	58	260	4	0	-	-
0057*	10	-	1021.3	57	47	-	69	300	2	0	-	-

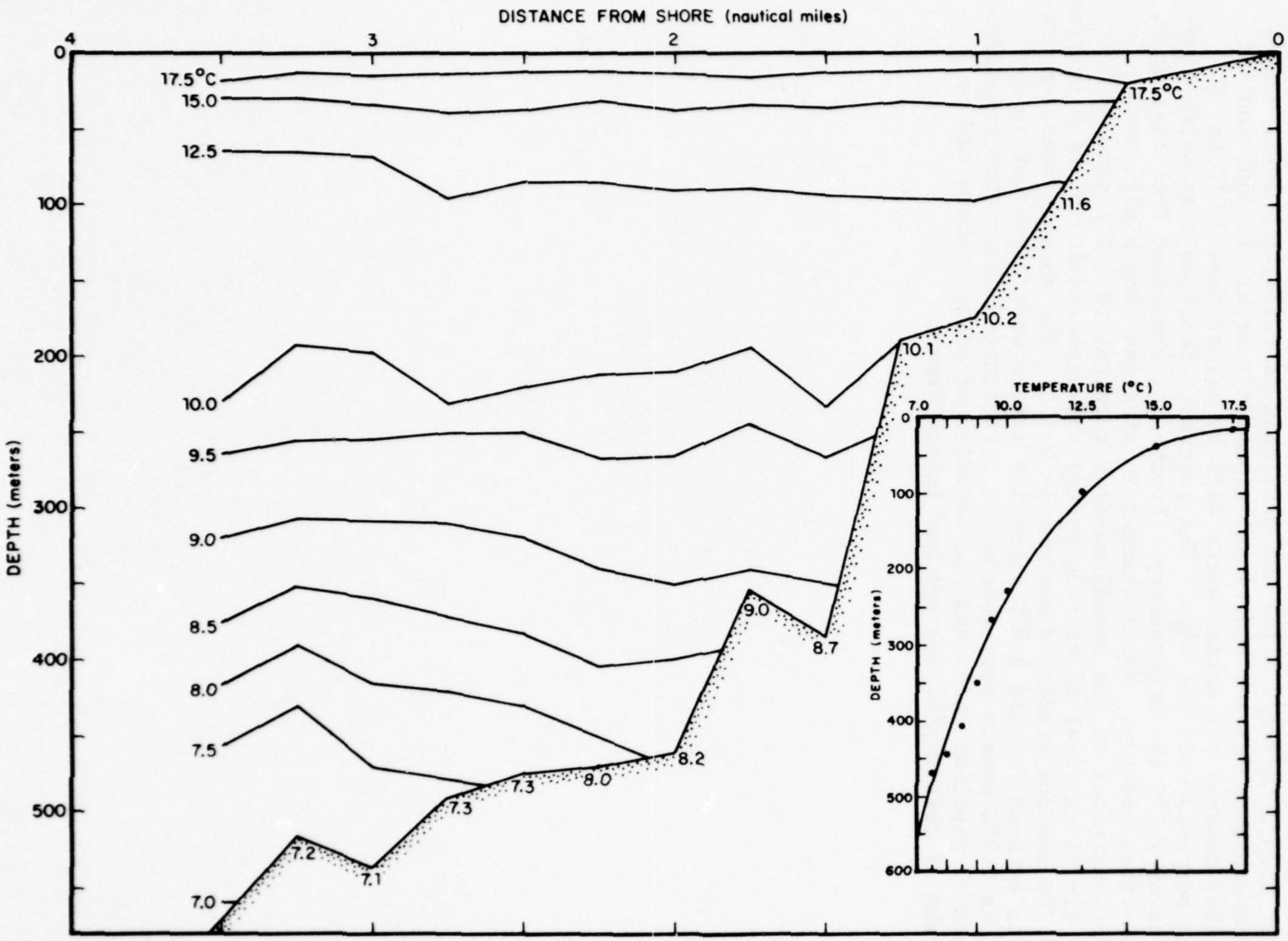


Figure 9.

Estimated maximum annual seawater temperature vs depth and distance offshore for the Point Mugu site. The insert figure presents the composite estimated maximum annual temperature vs depth profile constructed from the complete XBT data set.

approximately 1.4°C above the annual mean bottom temperatures are also anticipated for Stations 5-13. There is little advantage in extending the intake to distances greater than two nautical miles offshore. The slope is relatively flat from 2 to 3-1/2 miles out providing only slightly lower annual maximum temperatures for the additional pipeline length. In addition, at these greater depths, the intake water will be colder than 7.2°C an increasing percentage of the time. The contract specifies that water temperatures below 7.2°C are unnecessary. Proceeding shoreward from Station 7, the bottom rises steeply. Small changes in pipeline length will result in significant increases of the annual maximum temperature. For example, at Station 6 (1-3/4 nautical miles from shore) the expected annual mean temperature is 7.7°C and the predicted maximum is 9.1°C. The monthly mean temperature varies between 7.3 and 8.0°C, thus the intake water temperature may remain above 7.2°C nearly year round. An optimization study that considers the balance of pipeline costs and the benefits of colder waters may be a useful means of determining the optimum intake depth.

3.0 PEARL HARBOR SITE

3.1 Historical Data

The major source of bathythermographic data was NODC (National Oceanographic Data Center) records of mechanical bathythermographs (BT), expendable bathythermographs (XBT) and station data (consisting of continuous salinity-temperature-depth profiles and reversing thermometer measurements) for the area between 20-22°N and 157-159°W from 1944-1976[7]. Other sources included Oceanographic Atlases of the Pacific Ocean and Hawaiian Islands region[9,10,13], and discussions with Margaret K. Robinson (an authority on Pacific Ocean bathythermographic analysis)[8].

Table 8 and Figures 10 and 11 summarize the NODC data. At the surface, the mean monthly temperature reaches a maximum of 26.8°C in September and October and is generally above the annual average from June through November. The maximum observed temperature was 30.5°C on July 12, 1969. A surface layer of nearly constant temperature 50-100 meters deep is a typical feature. Below this layer is the main or permanent thermocline from 100-300 meters with an average temperature gradient of nearly 6°C/100m. From 300 meters to the bottom the temperature gradient gradually weakens. The mean temperature decreases from 11.6°C at 300 meters to 8.0°C at 425 meters.

Since bottom water temperature approaching 7.2°C within four nautical miles of the entrance to Pearl Harbor is the principal concern of this project, description of historical data will emphasize depths of 300 meters and greater. At the four-nautical mile survey limit, the water depth is approximately 420 meters. The mean annual temperature is 8.1°C and the monthly means vary from a maximum of 8.4°C in March to a minimum of 7.8°C in June. The maximum observed temperature of 11.9°C occurred on January 15, 1976. However, monthly maxima of 10.8°C and higher have also been observed in March, April, June, July and November. The average monthly maximum temperature is 10.5°C (2.4°C above the annual mean). Some of this large variability is probably attributable to the relatively large geographical area and diverse sampling instrumentation that have been combined to produce an estimate of conditions at the survey site. For this reason, the temperature structure at the survey site, and in particular the extreme values, can be expected to differ from these statistics. The annual maxima are estimated to be of the order of the average of the monthly maxima. The predicted annual maxima based on this assumption are given in Table 8 but the exact date and time of their occurrence is indeterminate from the existing data. The best available estimate is approximately the date of the observed maximum temperature. Clearly, this oversimplifies the problem as the data suggests that maxima of comparable magnitude may occur in the months of January, March, April, June, July and November.

Oceanographiic atlases[9,10,13] confirm the NODC annual means to within ±0.2°C for depths of 200, 300 and 400 meters but imply that these temperatures

Table 8

Summary of NODC Bathythermographic Data For the Area Between $20-22^{o}N$ and $157-159^{o}W$ From 1944-1976

Monthly Mean/ Maximum Temperature (°C)	Depth (m) 0	50	100	200	300	350	375	400	425
January	24.3/27.3	23.9/26.7	22.5/25.6	17.2/20.6	11.7/16.8	9.8/14.3	9.2/12.4	8.6/12.1	8.1/11.8
February	24.0/25.4	23.8/25.4	22.9/24.5	17.6/20.9	11.5/14.8	9.6/12.3	9.0/11.3	8.4/10.5	7.9/ 9.3
March	24.0/25.1	23.6/25.1	22.5/24.2	17.9/20.9	12.0/15.0	10.2/12.1	9.4/12.1	8.8/11.8	8.3/11.1
April	24.2/26.6	23.6/26.2	22.0/24.2	17.0/20.7	11.8/15.1	9.8/13.5	9.2/11.7	8.5/11.5	8.1/11.1
May	25.1/28.8	24.0/27.2	22.2/24.9	17.1/20.0	11.4/12.9	9.7/11.6	9.0/10.7	8.4/10.3	7.9/10.2
June	25.8/28.7	24.9/28.4	22.6/25.7	17.1/21.6	10.9/13.6	9.3/12.1	8.7/11.6	8.2/11.2	7.7/10.8
July	26.2/30.5	25.4/30.2	22.7/27.6	17.1/21.9	11.5/15.1	9.8/13.4	9.1/12.8	8.5/12.2	8.0/11.6
August	26.6/30.2	25.9/30.1	22.9/25.6	17.7/20.9	11.7/14.9	9.8/11.6	9.1/10.7	8.5/10.1	8.0/ 9.6
September	26.8/28.1	26.0/28.0	22.8/25.8	17.4/21.5	11.9/14.6	10.0/11.9	9.3/11.0	8.7/10.5	8.1/ 9.5
October	26.8/29.1	26.3/28.5	22.9/26.0	17.3/20.9	11.6/14.6	9.8/12.4	9.1/10.4	8.4/ 9.6	7.9/ 9.3
November	25.9/27.7	25.7/27.3	23.0/26.7	17.4/19.9	11.8/13.8	9.8/12.8	9.1/12.4	8.5/11.0	8.1/10.7
December	25.1/26.6	24.9/26.4	22.6/25.7	17.0/20.1	11.3/13.1	9.6/10.7	8.9/10.4	8.3/10.1	7.8/ 9.9
Annual Mean	25.4	24.8	22.6	17.3	11.6	9.8	9.1	8.5	8.0
Observed Maximum	30.5	30.2	27.6	21.9	16.8	14.3	12.8	12.2	11.8
Date(s) Ob.Max.	7/12/69	7/12/69	7/12/69	7/12/69	1/15/76	1/15/76	7/12/69	7/12/69	1/15/76
Predicted Annual Max. At Site	27.8	27.5	25.5	20.8	14.5	12.4	11.5	10.9	10.4

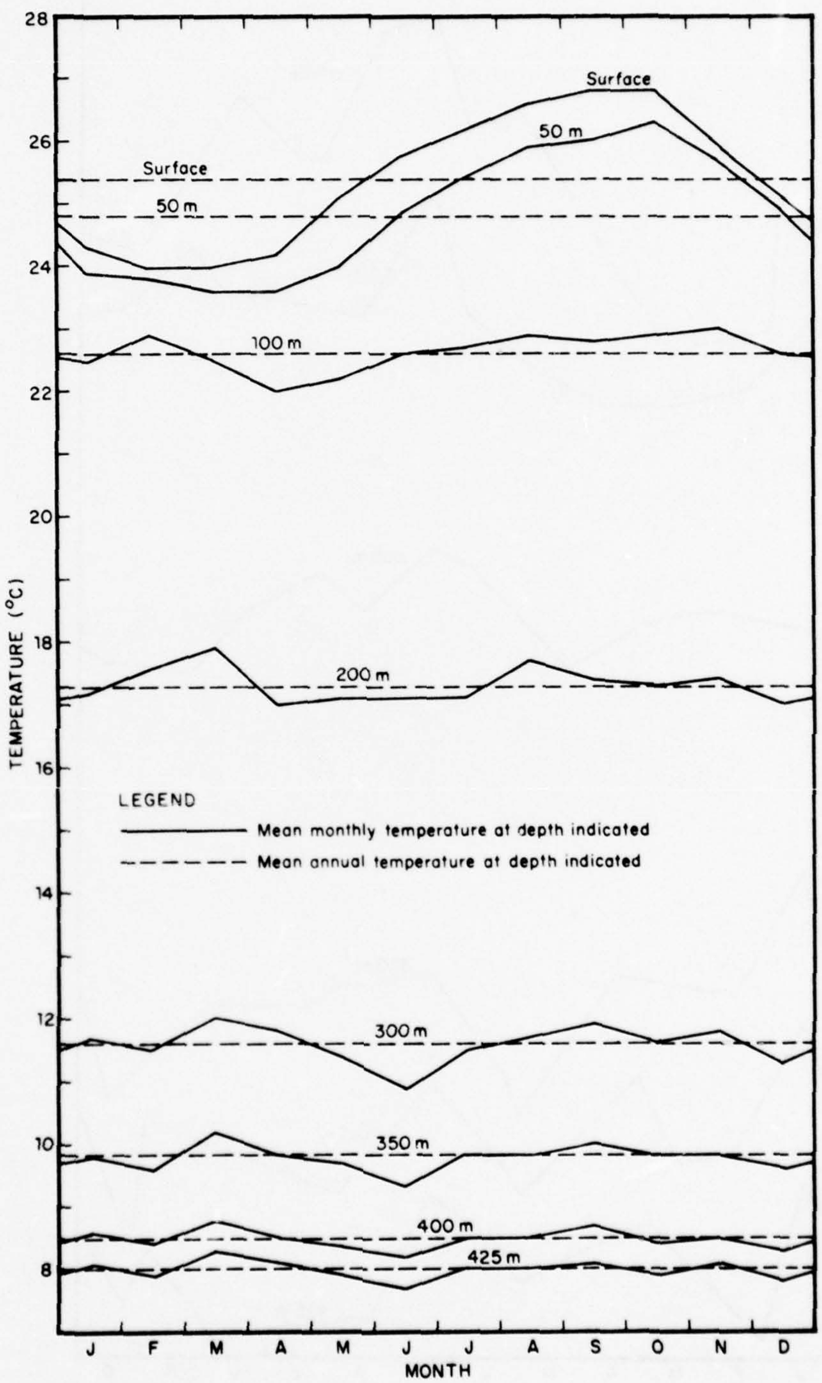


Figure 10.

Mean monthly water temperature for the area between 20-22°N and 157-159°W based on NODC data, 1944-1976.

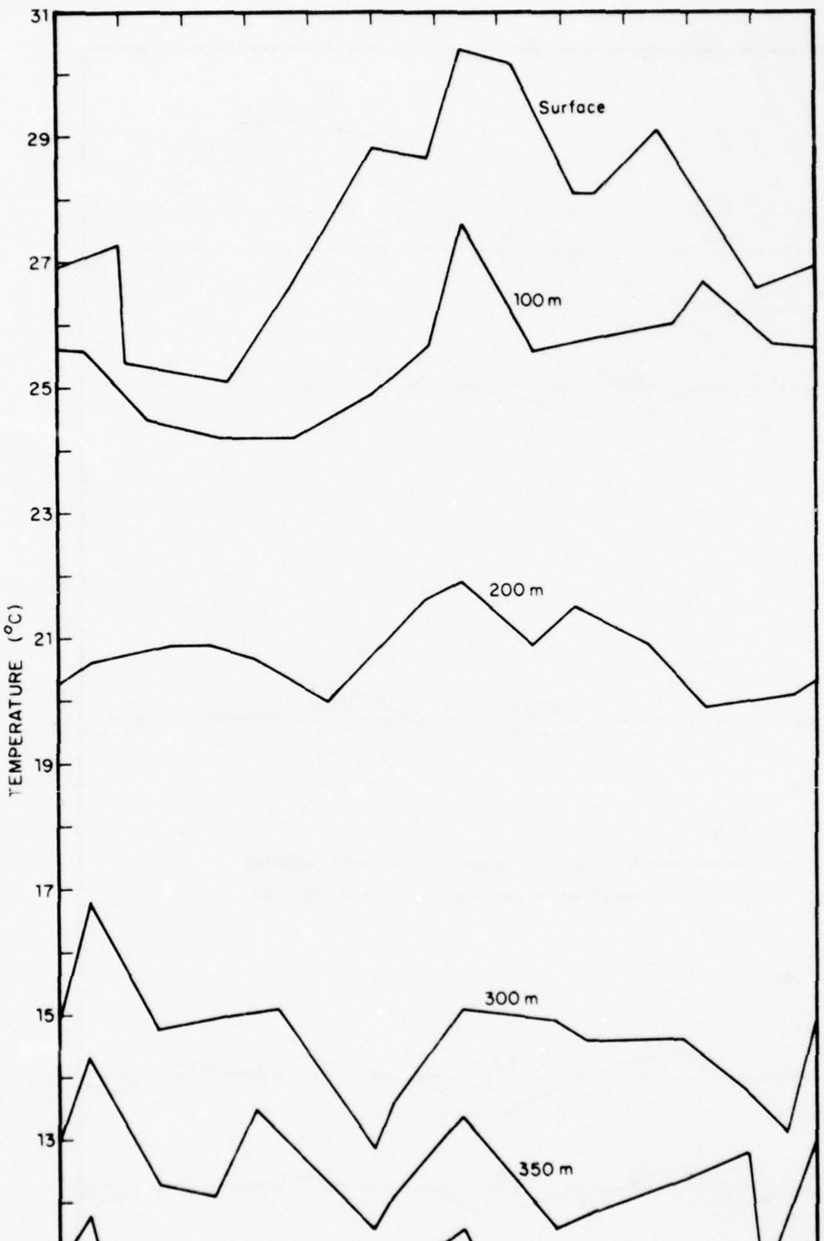


Figure 11.

Maximum monthly water temperature for the area between 20-22°N and 157-159°W based on NODC data, 1944-1976.

are constant year round, offering no insight to explain monthly maxima at 420 meters averaging 2.4°C above the annual mean. The following discussion evaluates the effects of some of the possible sources of temperature variation within the water column.

Diurnal (daily) variation of the water temperature due to absorption of incident solar energy can be as much as 3°C at the surface in August and may extend as deep as 10 meters but decreases rapidly as depth increases[3,4]. Variation should not be detectable as deep as 300 meters considering XBT sensitivity. At this latitude, seasonal variation in the amount of incident solar radiation is small, therefore variation among monthly mean water temperatures is generally less than 3°C at the surface and 0.6°C at 420 meters. Internal waves can be generated at the boundary between fluids of different density causing periodic vertical displacement of the isotherms. The strongest density gradient occurs within the main thermocline but internal waves can exist throughout the water column where vertically stratified conditions prevail. Internal waves have been observed with periods of approximately 6, 8, 12 and 24 hours and amplitudes of up to 5 meters[1]. At 200 meters (within the thermocline) this would contribute an additional variation of the order of ± 0.3°C about the mean. At 420 meters this variation would be reduced to ± 0.1°C. Based on a summation of the above mechanisms, the annual maximum would be expected to be less than 1.0°C above the annual mean. Other factors must exert strong influences to result in an annual maximum of 2-3°C above the mean. Proximity of even the deep station (420 meters) to the thermocline region is undoubtedly important. Variation in its vertical extent could significantly change the water temperature at a given location. Warm or cold water mass advection due to local current anomalies around the islands and in coastal areas may also be an important contributing factor. The XBT surveys should provide a valuable check of the predicted magnitude of the annual maximum but are not intended as an investigation of the mechanisms producing these maxima.

3.2 Survey Plan

Based on examination of the historical data, the estimated date of occurrence of the maximum annual bottom temperature at a depth of 420 meters is approximately the middle of January. Three XBT temperature surveys were conducted on December 23, 1978 and January 25 and February 16, 1979, approximately one month before, on the day of, and one month after the expected maximum bottom water temperature. Each survey consisted of a series of XBT deployments at 12 equally-spaced stations along a 180°True trackline extending from the east side of the entrance to Pearl Harbor (21°19'11"N, 157°57'30"W) to a distance of four nautical miles from shore.

The survey consisted of a single XBT deployment at each of the 12 stations and replicate observations at Station 12 (the farthest from shore) for several hours. The purpose of these repeated observations was to estimate the magnitude of the temperature variability over a short period of time (2-3 hours). In conjunction with the XBT deployments, surface meteorological observations were recorded. These consisted of measurement of sea surface temperature with a bucket thermometer, wet and dry bulb temperatures with a sling psychrometer,

wind speed and direction with a hand-held anemometer, sea state, percent cloud cover and present weather. These were supplemented with weather observations recorded by the National Weather Service at Honolulu International Airport.

Figure 12 indicates the positions of the 12 stations and the charted bathymetry from which the bottom profile in Figure 13 was drawn. The depths as determined in the surveys with a fathometer are also indicated for comparison. The Hawaii Institute of Geophysics bathymetric chart was based on NOAA-NOS (National Oceanic and Atmospheric Administration-National Ocean Survey) data and contoured every 5 meters(5). For the most part, the chart depth exceeded the measured depth by less than 20 meters, except at Station 3 where the chart depth was 49 meters greater than the measured depth in an area with a steeply sloping bottom. Table 9 gives the position and estimated and measured depths of the 12 assigned stations.

3.3 Instrumentation

Instrumentation for the Pearl Harbor area surveys was essentially the same as the Point Mugu area surveys (Chapter 2.3). The only difference was that station positioning was accomplished by taking simultaneous horizontal sextant angles between three known landmarks. The angles were then plotted on NOAA-NOS Chart Number 19364 with a three arm protractor to establish the ship's position. This system was selected based on examination of climatological statistics of Honolulu, Hawaii(3,4). Weather severe enough to interfere with shipping or travel and reduction of surface visibility to less than five miles are uncommon. Small errors in positioning will have minimal effect on temperatures at Stations 5-12. The bottom slope is relatively gentle and the contours approximately parallel the coastline. There are no significant features, such as deep canyons or plateaus in the vicinity of the trackline.

3.4 Presentation of Data and Discussion of Results

Copies of the XBT traces of the three Pearl Harbor surveys are given in Figures 14, 15 and 16. Each is identified by station number, date and time. Measured sea surface temperature is also included. All XBT's were within 61 meters of the assigned stations in Figure 12. In some of the original traces the depth of the water column was clearly indicated by a horizontal trace (increase or decrease in temperature at a constant depth) followed by a nearly vertical trace (little change in temperature as depth apparently increases). However, when this was not a dependable method of depth determination, the traces were truncated at the measured bottom depth. The surface and bottom temperatures and the depths of the 22.5, 20.0, 17.5, 15.0, 12.5, 12.0, 11.5, 11.0, 10.5, 10.0, 9.5, 9.0, 8.5 and 8.0°C isotherms of all the XBT's are summarized in Table 10. Shipboard weather observations are summarized in Tables 11, 12 and 13 and supplemented with observations recorded by the National Weather Service Station at Honolulu, Hawaii.

Figure 17 was constructed by plotting the maximum observed depth of each isotherm at each station and joining these points. The maximum

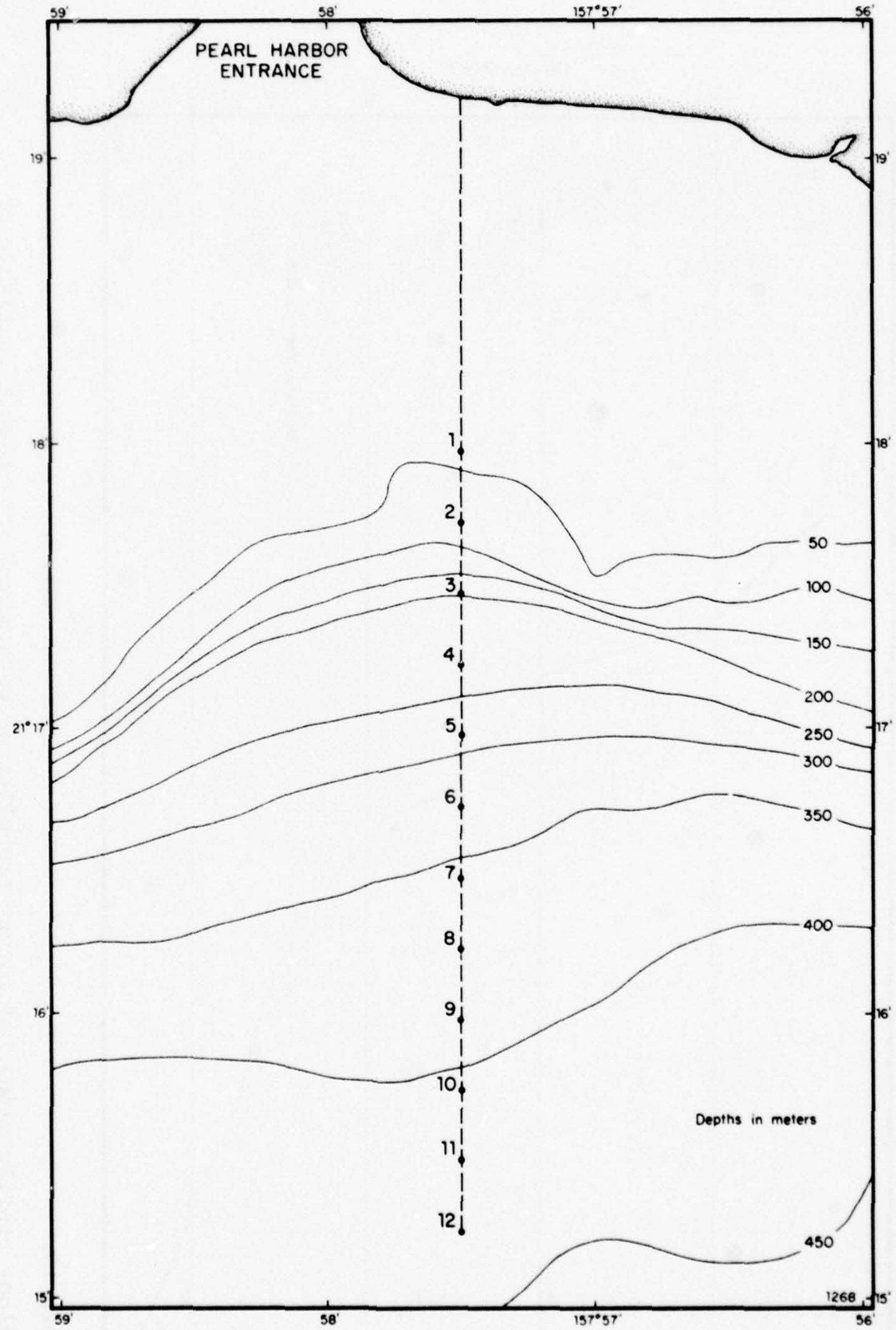


Figure 12.

Location of XBT deployments for Pearl Harbor surveys December 23, 1978, January 25 and February 16, 1979 and existing bathymetry based on Hawaii Institute of Geophysics chart.

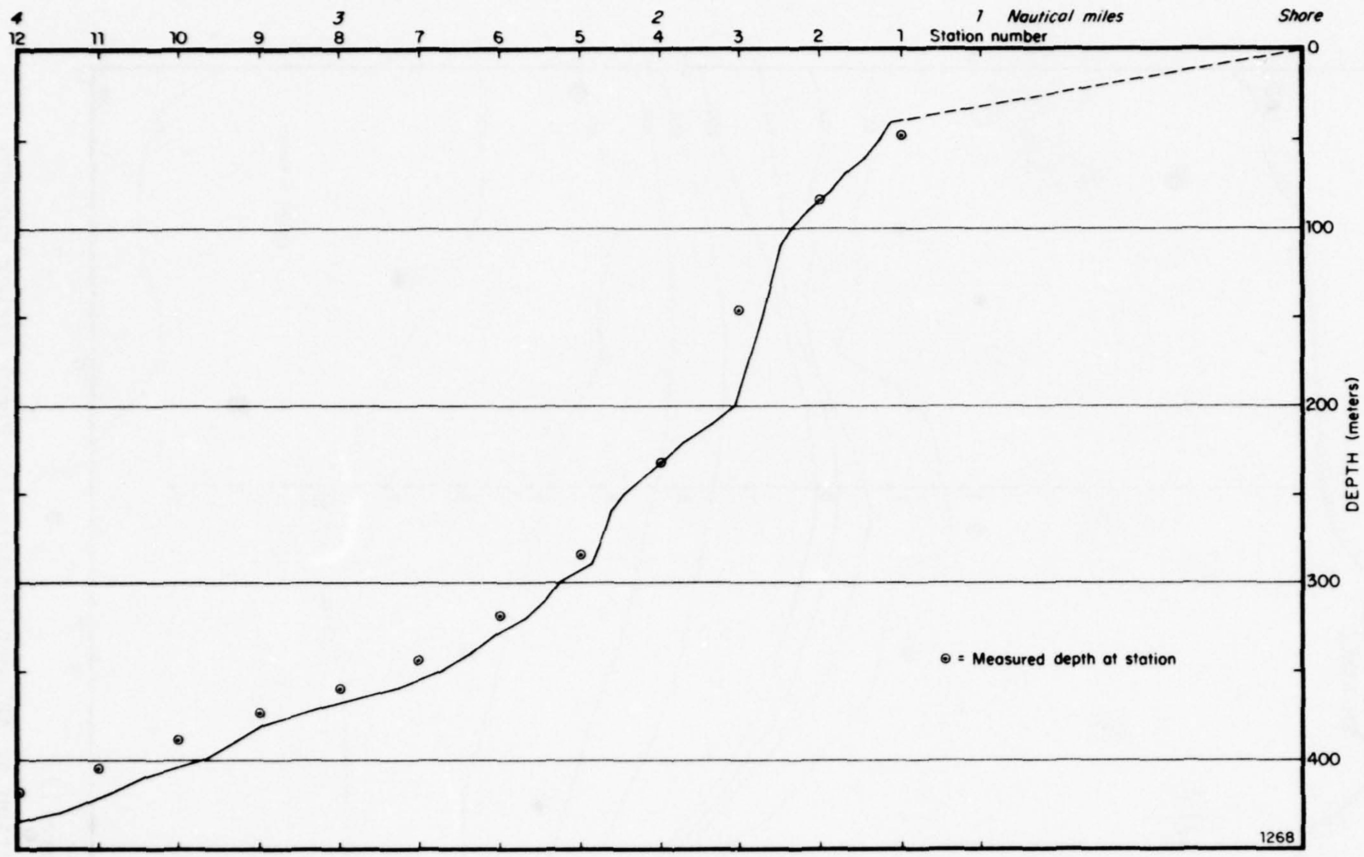


Figure 13.

Seafloor profile along XBT survey trackline as determined from Hawaii Institute of Geophysics chart and fathometer-measured depths.

Table 9

Pearl Harbor XBT Survey Station Locations, Depths and Expected Bottom Temperatures Based on Historical Data

Station Number	Distance Along 180° Trackline (n.m.)	Latitude	Longitude	Chart Depth (w) Hawaii Institute of Geophysics	Measured Depth (m)	Bottom Temperatures (°C) Annual Mean	Bottom Temperatures (°C) Estimated Annual Maximum
1	1.25	21°17'56"N	157°57'30"W	35	48	24.8	27.5
2	1.50	21°17'41"N	157°57'30"W	85	84	23.4	26.2
3	1.75	21°17'26"N	157°57'30"W	195	146	20.2	23.4
4	2.00	21°17'11"N	157°57'30"W	232	233	15.4	18.7
5	2.25	21°16'56"N	157°57'30"W	293	285	12.4	15.4
6	2.50	21°16'41"N	157°57'30"W	328	319	10.8	13.6
7	2.75	21°16'26"N	157°57'30"W	355	344	10.0	12.6
8	3.00	21°16'11"N	157°57'30"W	368	360	9.5	12.0
9	3.25	21°15'56"N	157°57'30"W	382	374	9.2	11.6
10	3.50	21°15'41"N	157°57'30"W	404	389	8.8	11.2
11	3.75	21°15'26"N	157°57'30"W	422	405	8.4	10.8
12	4.0	21°15'11"N	157°57'30"W	435	419	8.1	10.5

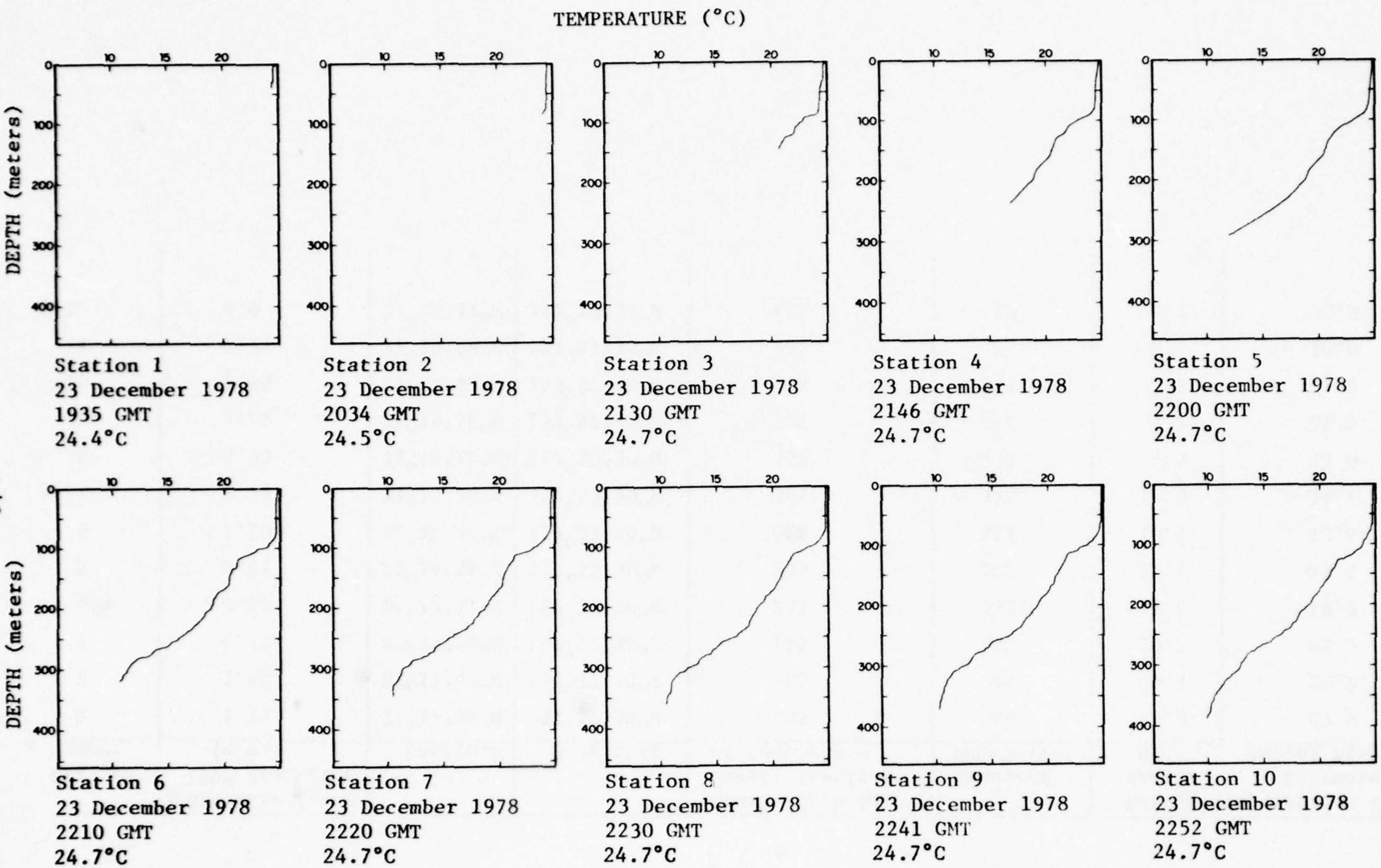


Figure 14.

XBT traces of December 23-24, 1978 survey at Pearl Harbor, Hawaii and observed bucket thermometer sea surface temperatures.

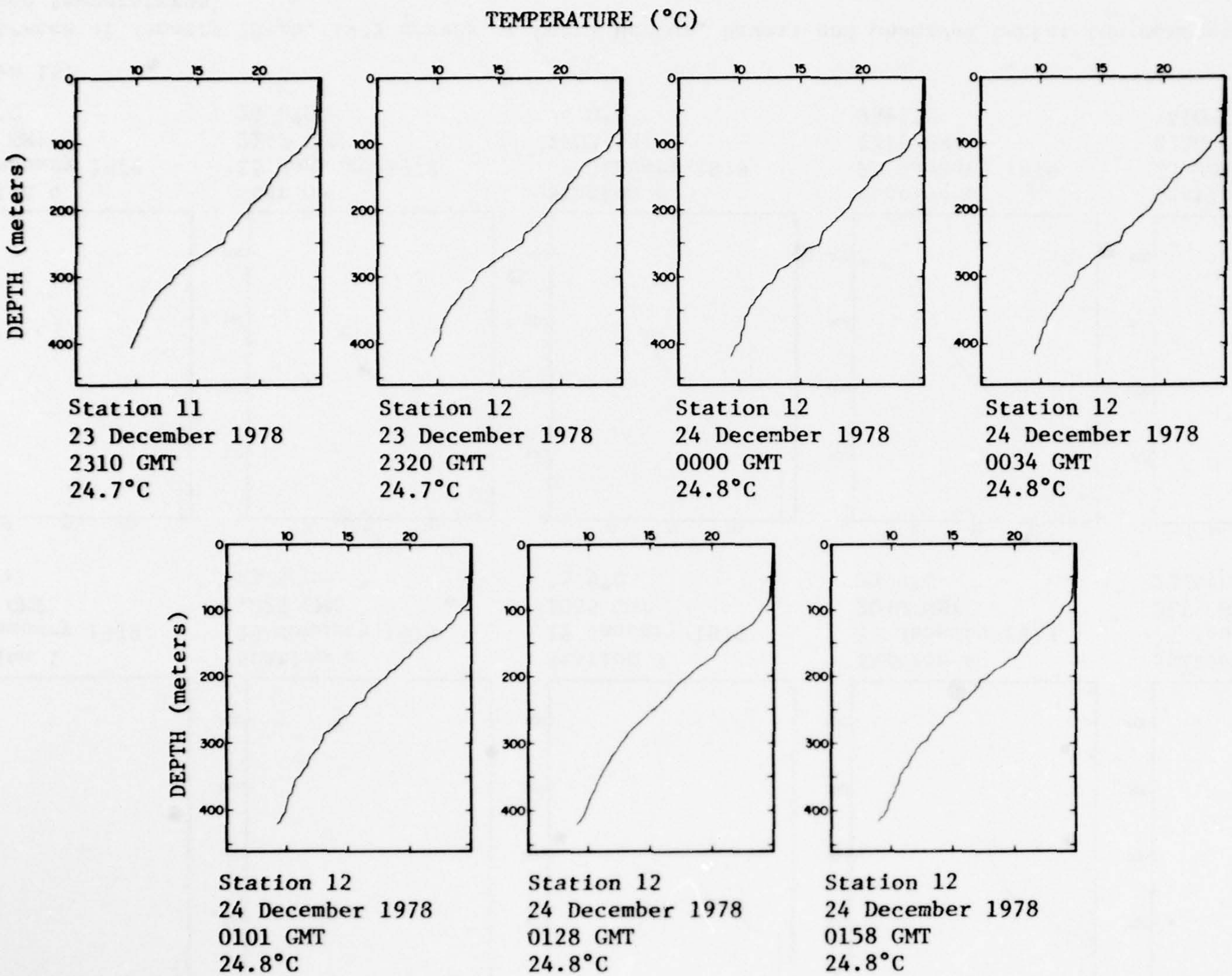
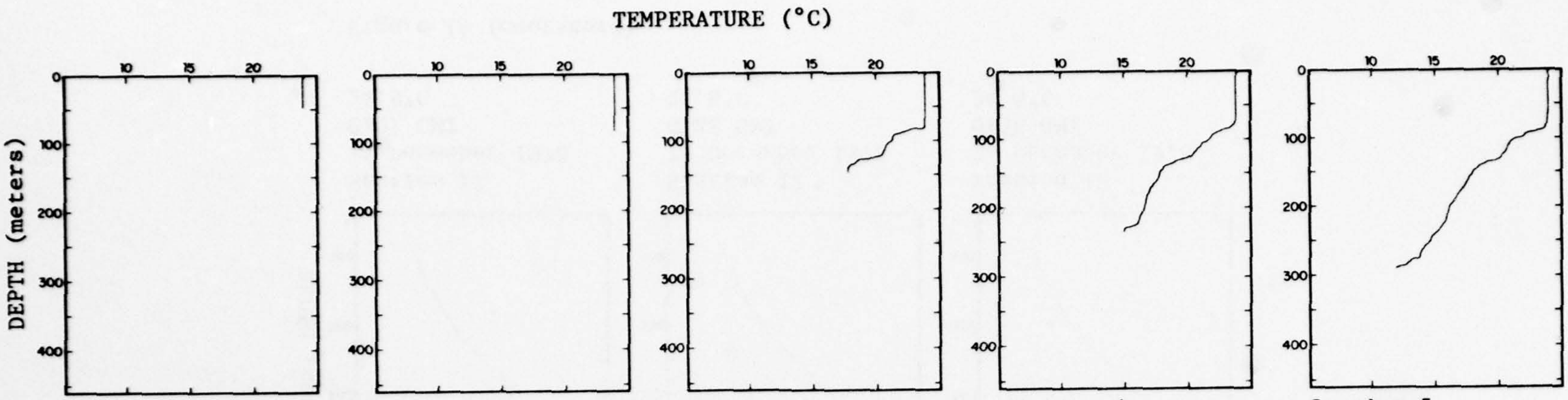


Figure 14 (continued)



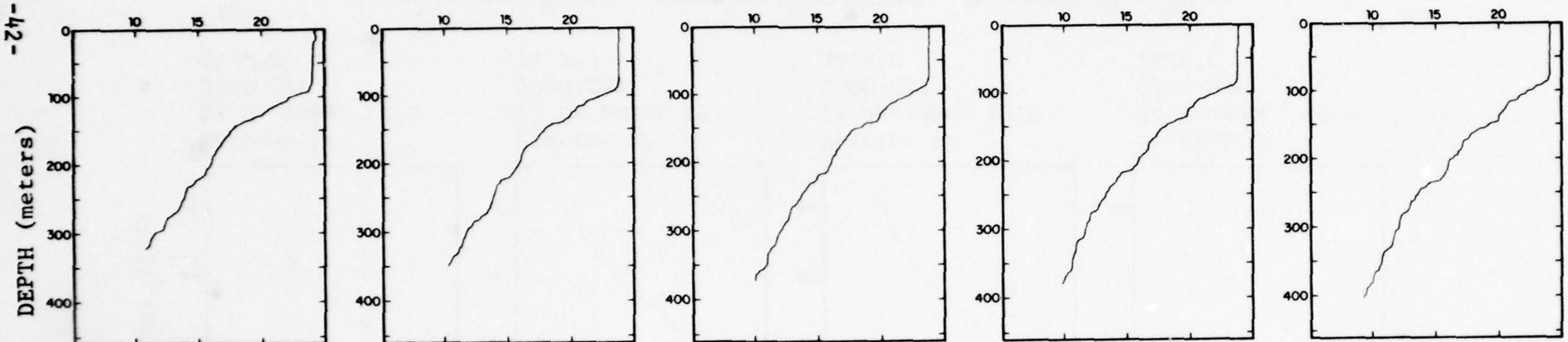
Station 1
25 January 1979
2003 GMT
23.8°C

Station 2
25 January 1979
2025 GMT
23.9°C

Station 3
25 January 1979
2035 GMT
23.9°C

Station 4
25 January 1979
2050 GMT
23.9°C

Station 5
25 January 1979
2115 GMT
23.9°C



Station 6
25 January 1979
2135 GMT
24.0°C

Station 7
25 January 1979
2147 GMT
24.0°C

Station 8
25 January 1979
2203 GMT
24.0°C

Station 9
25 January 1979
2216 GMT
23.9°C

Station 10
25 January 1979
2230 GMT
24.0°C

Figure 15.

XBT traces of January 25-26, 1979 survey at Pearl Harbor, Hawaii and observed bucket thermometer sea surface temperatures.

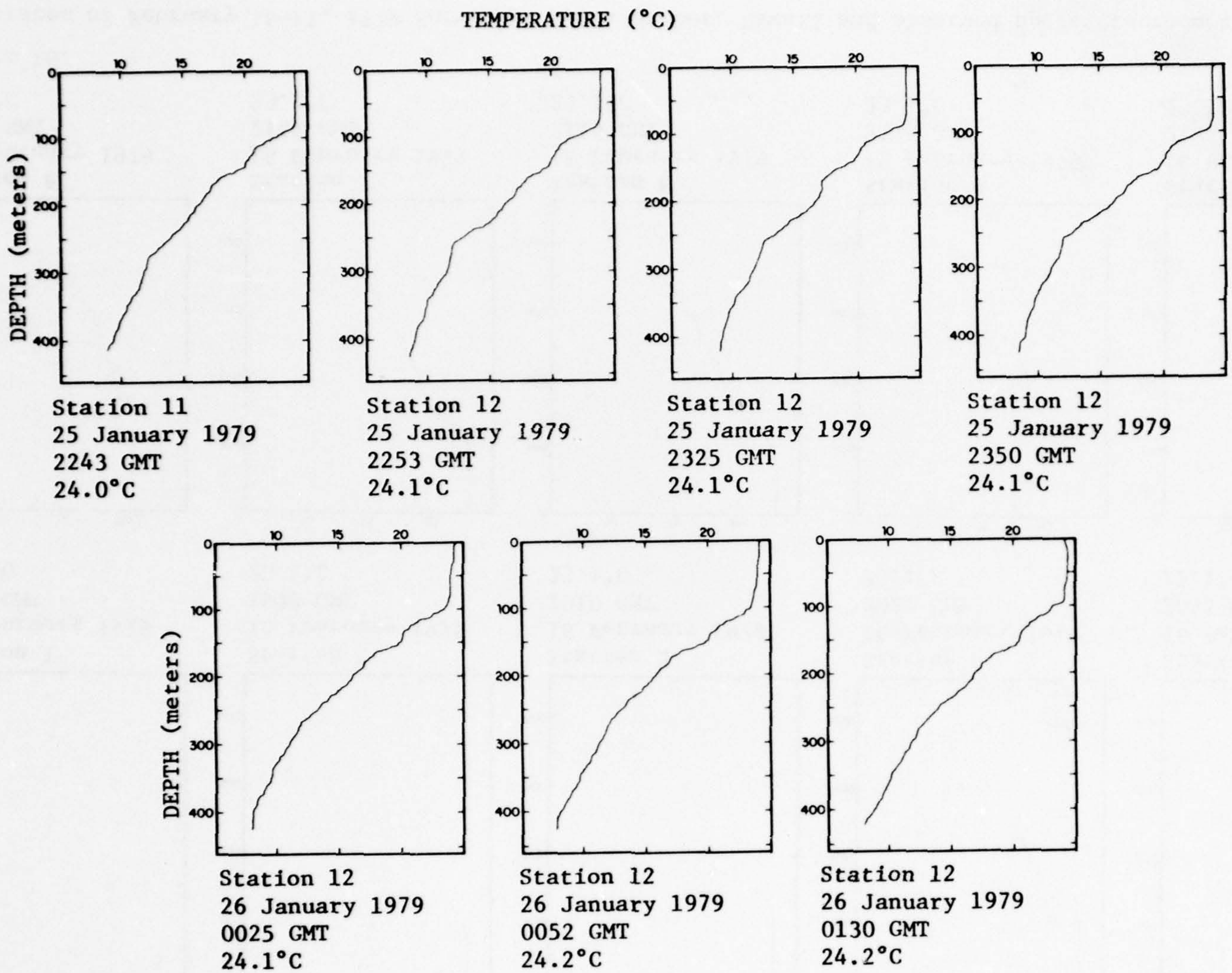


Figure 15 (continued)

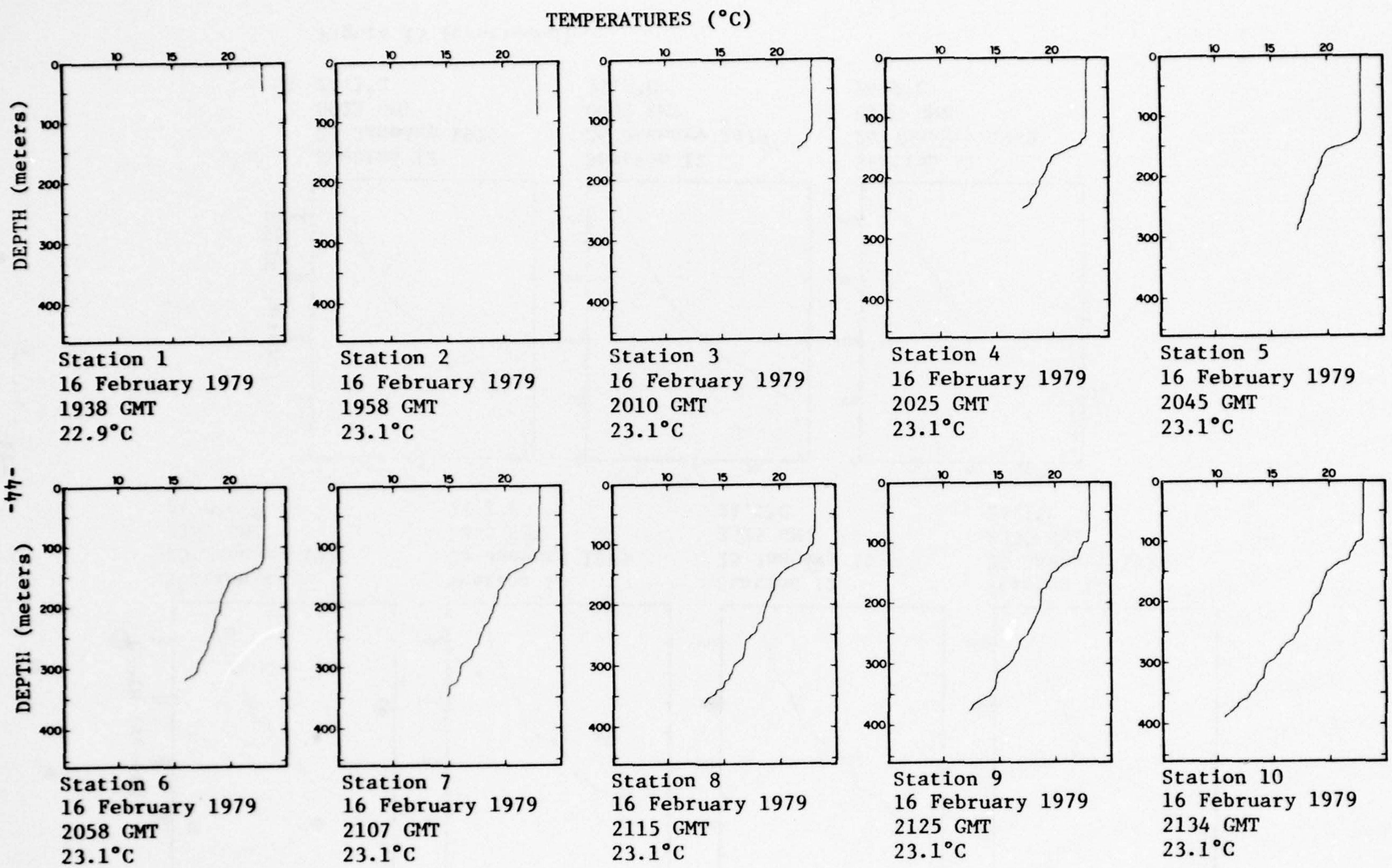
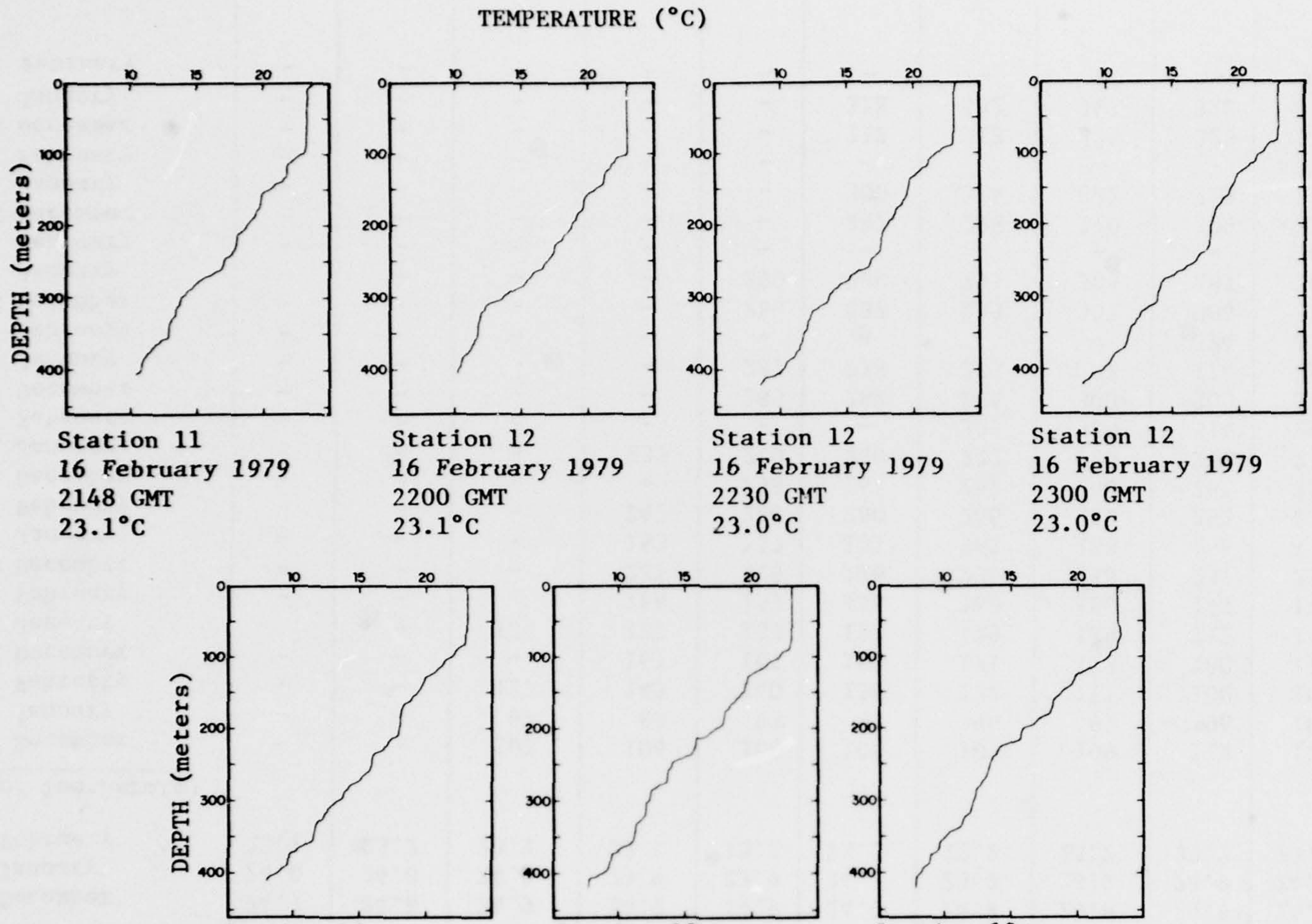


Figure 16.

XBT traces of February 16-17, 1979 survey at Pearl Harbor, Hawaii and observed bucket thermometer sea surface temperatures.



Station 11
16 February 1979
2148 GMT
23.1°C

Station 12
16 February 1979
2200 GMT
23.1°C

Station 12
16 February 1979
2230 GMT
23.0°C

Station 12
16 February 1979
2300 GMT
23.0°C

Station 12
16 February 1979
2329 GMT
23.1°C

Station 12
16 February 1979
2359 GMT
23.1°C

Station 12
17 February 1979
0033 GMT
23.1°C

Figure 16 (continued)

Table 10

Summary of Monthly XBT Survey Data: Surface Temperature, Bottom Temperature and Depth of Selected Isotherms

	Station Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Surface Temperature (^{o}C)												
December	24.7	24.6	24.9	24.9	24.9	24.9	24.8	24.8	24.9	24.9	24.8	24.9
January	24.0	24.0	24.0	23.9	23.9	24.2	23.9	23.9	23.9	24.1	24.0	24.1
February	23.1	23.2	23.2	23.1	23.2	23.2	23.2	23.2	23.2	23.1	23.2	23.2
Depth of Isotherm(m)												
22.5^{o}C December	-	-	102	106	108	108	107	109	112	121	127	125
January	-	-	87	88	93	97	99	99	96	100	100	96
February	-	-	137	143	140	136	122	111	100	100	106	103
20.0^{o}C December	-	-	-	167	167	169	171	175	180	173	181	185
January	-	-	124	127	133	127	129	129	122	144	143	136
February	-	-	-	166	157	156	160	150	149	147	153	157
17.5^{o}C December	-	-	-	225	226	226	235	238	237	234	230	232
January	-	-	-	163	157	151	162	158	156	172	168	174
February	-	-	-	247	280	280	266	250	252	235	243	238
15.0^{o}C December	-	-	-	-	258	262	257	268	261	267	272	273
January	-	-	-	235	240	220	222	220	216	234	231	230
February	-	-	-	-	-	-	333	328	314	296	280	287
12.5^{o}C December	-	-	-	-	285	282	284	300	300	313	314	317
January	-	-	-	-	287	278	283	287	274	281	273	255
February	-	-	-	-	-	-	-	-	374	359	357	311
12.0^{o}C December	-	-	-	-	289	287	293	307	306	320	322	327
January	-	-	-	-	290	294	293	303	287	303	294	273
February	-	-	-	-	-	-	-	-	-	364	363	330
11.5^{o}C December	-	-	-	-	-	297	298	310	309	328	333	338
January	-	-	-	-	-	300	314	322	313	329	322	302
February	-	-	-	-	-	-	-	-	-	375	374	363
11.0^{o}C December	-	-	-	-	-	312	318	325	323	341	349	350
January	-	-	-	-	-	318	332	347	320	336	332	314
February	-	-	-	-	-	-	-	-	-	384	384	377

Table 10 (continued)

Depth of Isotherm(m) continued		Station Number 1	2	3	4	5	6	7	8	9	10	11	12
$10.5^{o}C$	December	–	–	–	–	–	–	330	362	351	355	366	364
	January	–	–	–	–	–	–	342	356	359	357	350	333
	February	–	–	–	–	–	–	–	–	–	–	403	392
$10.0^{o}C$	December	–	–	–	–	–	–	–	–	–	382	386	398
	January	–	–	–	–	–	–	–	370	373	380	368	352
	February	–	–	–	–	–	–	–	–	–	–	–	–
$9.5^{o}C$	December	–	–	–	–	–	–	–	–	–	–	–	418
	January	–	–	–	–	–	–	–	–	–	396	389	377
	February	–	–	–	–	–	–	–	–	–	–	–	–
$9.0^{o}C$	December	–	–	–	–	–	–	–	–	–	–	–	–
	January	–	–	–	–	–	–	–	–	–	–	404	400
	February	–	–	–	–	–	–	–	–	–	–	–	–
$8.5^{o}C$	December	–	–	–	–	–	–	–	–	–	–	–	–
	January	–	–	–	–	–	–	–	–	–	–	–	–
	February	–	–	–	–	–	–	–	–	–	–	–	–
$8.0^{o}C$	December	–	–	–	–	–	–	–	–	–	–	–	–
	January	–	–	–	–	–	–	–	–	–	–	–	–
	February	–	–	–	–	–	–	–	–	–	–	–	–
Bottom Temperature (^{o}C)													
	December	24.6	24.4	20.7	16.8	11.9	10.7	10.5	10.5	10.1	9.8	9.7	9.3
	January	23.8	23.9	17.8	15.0	12.0	10.8	10.3	10.0	9.9	9.2	8.9	8.6
	February	23.1	23.0	21.8	17.3	17.3	15.9	14.8	13.3	12.3	10.7	10.4	10.2

Table 10 (continued)

	Station Number				
	12	12	12	12	12
Surface Temperature (°C)					
December	25.0	25.0	25.0	25.0	24.9
January	24.1	24.2	24.2	24.2	24.2
February	23.2	23.1	23.1	23.1	23.0
Depth of Isotherm (m)					
22.5°C December	125	131	136	130	128
January	99	105	107	113	113
February	91	86	87	82	95
20.0°C December	172	172	169	172	173
January	134	147	146	149	160
February	133	130	129	124	124
17.5°C December	221	221	210	207	204
January	167	177	171	170	185
February	237	237	213	200	183
15.0°C December	270	265	257	254	254
January	226	221	219	216	235
February	280	273	273	240	222
12.5°C December	312	317	312	306	300
January	263	253	262	263	279
February	318	330	315	286	283
12.0°C December	319	325	322	319	316
January	290	263	272	278	298
February	346	343	328	322	318
11.5°C December	332	339	338	334	330
January	308	290	288	296	312
February	367	370	352	329	323
11.0°C December	345	350	350	350	342
January	328	307	301	313	330
February	383	374	360	358	339
10.5°C December	361	365	367	370	363
January	337	320	315	329	340
February	388	383	363	362	342
10.0°C December	400	390	392	390	383
January	355	339	326	338	361
February	403	395	371	368	350
9.5°C December	414	416	416	410	405
January	380	364	353	360	375
February	408	402	389	374	368

	Station Number				
	12	12	12	12	12
Depth of Isotherm (m)					
9.0°C December	-	-	420	420	413
January	420	390	380	372	393
February	410	405	396	399	374
8.5°C December	-	-	-	-	-
January	-	410	422	390	[illegible]
February	418	416	401	403	392
8.0°C December	-	-	-	-	-
January	-	-	-	403	420
February	-	-	410	406	405
Bottom Temperature (°C)					
December	9.4	9.5	9.0	9.0	8.9
January	9.0	8.4	8.0	7.8	8.0
February	8.3	8.1	8.0	7.7	7.8

Table 11

Summary of December 23-24, 1978 Surface Meteorological Observations

Time (GMT)	Surface Visibility (st.mi.)	Weather	Sea Level Pressure (mb)	Air Temperature (^oF)	Dew Point (^oF)	Wet Bulb Temp. (^oF)	Relative Humidity (%)	Wind Dir. (^{o})	Wind Speed (kts)	Sky Cover (10ths)	Sea Surface Temp (^oC)	Sea State
1940	20	Rain Showers	-	73.5	-	72	89	12	3	6	24.4	2
1955*	20	Rain Showers	1014.8	69	63	-	81	70	4	8	-	-
2040	20	Rain Showers	-	74.5	-	72	83	17	4	7	24.5	2
2055*	25	-	1014.4	72	64	-	77	350	7	7	-	-
2150	20	-	-	73	-	69	74	37	4	4	24.7	2
2155*	25	-	1013.5	72	62	-	71	60	6	7	-	-
2255	20	-	-	75	-	73	87	42	7	3	24.7	2
2255*	25	-	1012.1	75	61	-	62	80	10	6	-	-
2355*	25	-	1011.1	75	59	-	58	30	12	6	-	-
0000	20	-	-	75	-	72	80	42	12	3	24.8	2
0055*	25	-	1010.7	73	59	-	61	60	11	7	-	-
0100	20	-	-	74.5	-	73	90	42	9	4	24.8	3
0155*	25	-	1010.6	73	60	-	65	40	10	8	-	-
0200	20	-	-	74	-	71.5	83	42	9	4	24.7	3

*National Weather Service Honolulu Observations.

Table 12

Summary of January 25-26, 1979 Surface Meteorological Observations

Time (GMT)	Surface Visibility (st.mi.)	Weather	Sea Level Pressure (mb)	Air Temperature (^{o}F)	Dew Point (^{o}F)	Wet Bulb Temp. (^{o}F)	Relative Humidity (%)	Wind Dir. (^{o})	Wind Speed (kts)	Sky Cover (10ths)	Sea Surface Temp (^{o}C)	Sea State
1955*	25	-	1015.8	71	61	-	71	100	10	6	-	-
2005	15	-	-	76	-	69	58	72	13	4	23.8	3
2055*	25	-	1015.8	75	62	-	64	100	11	4	-	-
2120	15	-	-	75	-	69	63	107	20	5	23.9	3
2155*	25	-	1015.3	73	61	-	66	90	10	6	-	-
2205	20	-	-	74	-	69	67	97	15	4	24.0	3
2255*	25	-	1014.5	74	62	-	66	90	10	6	-	-
2307	20	-	-	78	-	70	53	107	18	6	24.1	3
2355*	25	-	1013.8	76	62	-	62	60	10	8	-	-
0005	20	-	-	76	-	71	68	102	12	5	24.0	3
0055*	25	-	1013.6	77	62	-	60	80	15	8	-	-
0155*	25	-	1013.8	76	63	-	64	50	16	4	-	-

*National Weather Service Honolulu Observations.

Table 13

Summary of February 16-17, 1979 Surface Meteorological Observations

Time (GMT)	Surface Visibility (st.mi.)	Weather	Sea Level Pressure (mb)	Air Temperature (^{o}F)	Dew Point (^{o}F)	Wet Bulb Temp. (^{o}F)	Relative Humidity (%)	Wind Dir. (^{o})	Wind Speed (kts)	Sky Cover (10ths)	Sea Surface Temp (^{o}C)	Sea State
1855*	25	-	1017.7	72	65	-	79	60	7	10	-	-
1940	15	-	-	73.5	-	70	68	72	4	10	22.9	2
1955*	25	-	1017.8	72	65	-	79	70	9	10	-	-
2048	15	-	-	74	-	69	67	67	6	10	23.0	2
2055*	25	-	1017.8	74	65	-	74	70	13	10	-	-
2150	18	-	-	74	-	70	68	82	3.5	10	23.0	2
2155*	25	-	1017.2	75	65	-	71	60	10	10	-	-
2245	15	-	-	74	-	70	68	77	13	10	22.9	3
2255*	25	-	1016.2	76	65	-	69	80	14	10	-	-
2345	18	-	-	74	-	69	67	(80)	17	10	22.9	3
2355*	25	-	1015.4	75	64	-	69	70	14	10	-	-
0040	15	-	-	73	-	69	67	82	18	10	23.0	3
0055*	25	-	1015.0	75	65	-	71	70	10	10	-	-

*National Weather Service Honolulu Observations.

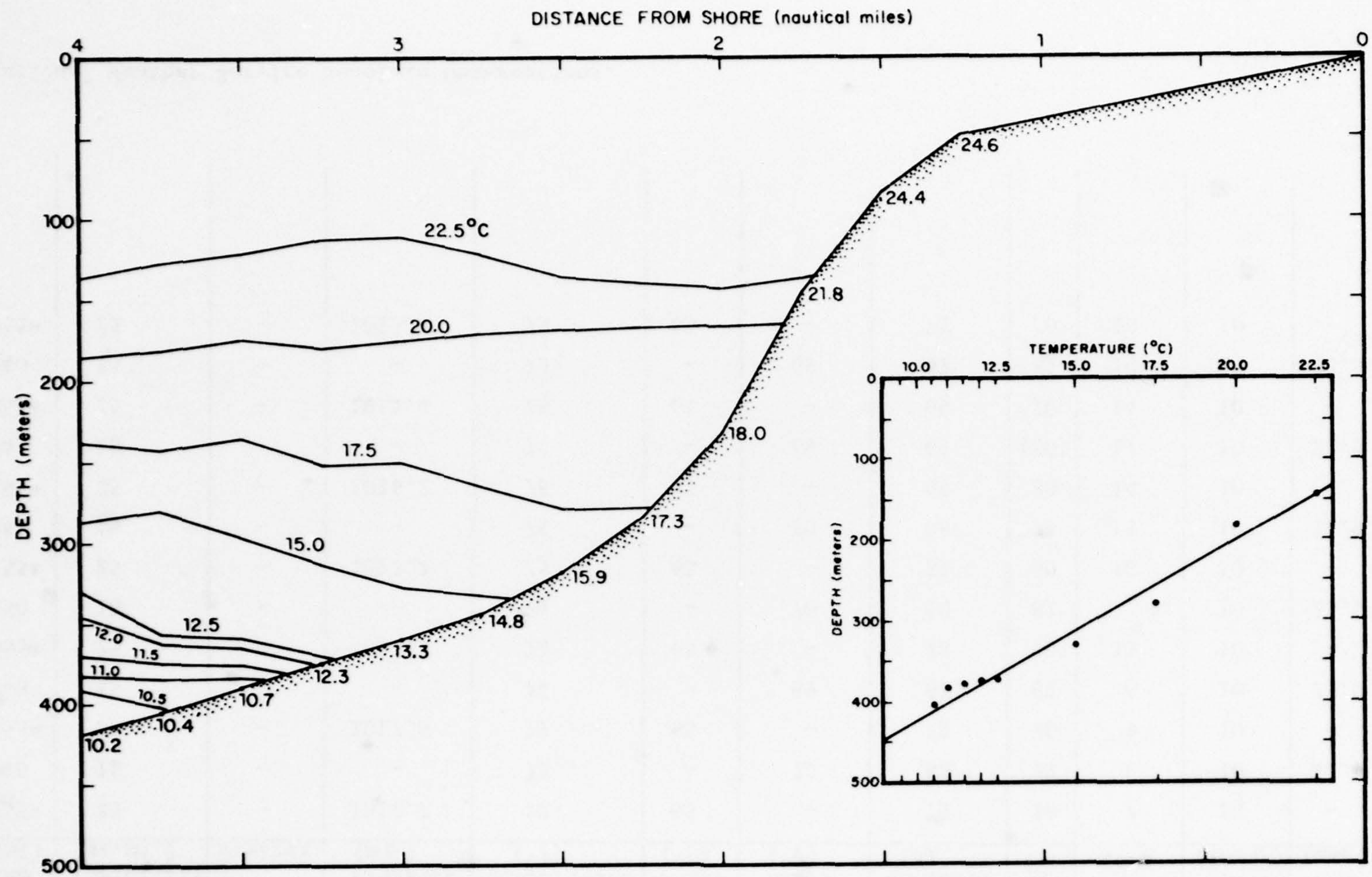


Figure 17.

Estimated maximum annual sea water temperature vs depth and distance offshore for Pearl Harbor site. (The insert figure presents the composite estimated maximum annual temperature vs depth profile constructed from the complete XBT data set.)

recorded bottom temperatures are also indicated. At Stations 3-12, these maxima were recorded during the February 16 survey and constitute the best available estimates of the maximum sea water temperatures as a function of depth and distance offshore. Although the annual maximum bottom temperatures were anticipated in January, the results of this survey and historical data suggest that maxima of comparable magnitude may also occur a number of times throughout the year. Based on the available data, no estimate of the duration of these maximum temperature events is possible. However, at Station 12, bottom water temperature variations between 8.9 and 9.5°C in December, 7.8 and 9.0°C in January, and 7.7 and 10.2°C in February, were experienced within a 2-3 hour period. Variability of this magnitude (due to environmental changes and instrument uncertainty) can be expected at Stations 5-12. It is conceivable that dependence on a single XBT deployment at each station (except Station 12) may have resulted in underestimation of of the maximum water temperatures by 1°C or more. An alternative method of displaying the XBT data is to construct a composite maximum temperature versus depth profile representative of all the stations by assembling the greatest measured depth of each isotherm into a single curve (Figure 17 insert). This curve estimates maximum annual bottom temperatures for Stations 5-12 that range from .4°C lower (at Station 12) to 1.1°C higher (at Station 6) than the estimates based on historical data in Table 9.

3.5 Conclusions

To summarize, bottom temperatures as low as 7.2°C are not obtainable within four nautical miles of shore. The surveys showed that the observed maximum bottom temperature at Station 12 (420 meters) of 10.2°C occurred in February. This was 2.1°C above the expected annual mean of 8.1°C and 0.3°C below the predicted annual maximum of 10.5°C (Table 9). At this depth, the monthly mean temperatures are expected to vary between 8.4°C in March and 7.8°C in June. Maxima of approximately 2.0°C above the annual mean bottom temperatures are also anticipated for Stations 10 and 11. At Stations 5 through 9, the observed maxima are 3°C - 5°C above the annual means, closely approximating the NODC observed maxima.

There is minimal advantage in extending the intake to distances greater than three and one half nautical miles from shore. The difference in maxima between Stations 10 and 12 is on the order of 0.5°C. Proceeding shoreward from Station 10, the bottom temperatures increase more rapidly and small changes in pipeline length could result in significant increases in the annual maximum temperature.

In addition, greater variability can be expected when these stations fall within the thermocline region. An optimization study that considers the balance of pipeline costs and the benefits of colder water, may be a useful means of determining the optimum intake depth.

REFERENCES

1. Cairns, J.L., and E.C. LaFond, 1966. Periodic motion of the seasonal thermocline along the Southern California coast. Journal of Geophysical Research, Vol. 70, No.16, p. 3903-3915.

2. Department of the Navy, Naval Weather Service Environmental Detachment, 1971. Climatological study of Southern California operating area. Naval Weather Service Command, Asheville, North Carolina, 242 p.

3. Department of the Navy, Naval Weather Service Environmental Detachment, 1977. Climatological, astronomical and tidal data for the Hawaiian Islands for 1978. Naval Air Station, Barbers Point, Hawaii, 43 p.

4. Department of the Navy, Naval Weather Service Environmental Detachment, 1978. Climatological, astronomical and tidal data for the Hawaiian Islands for 1979. Naval Air Station, Barbers Point, Hawaii, 51 p.

5. Hawaii Institute of Geophysics, 1965. Oahu: Submarine topography from Ewa Beach to Honolulu Harbor entrance.

6. Horrer, Paul L. and Associates, 1952. Certain oceanographic conditions relative to offshore drilling in Southern California coastal waters, 108 p.

7. National Oceanographic Data Center (NODC), Washington, D.C. Oceanographic station data (SD), Mechanical bathythermograph (MBT) and Expendable bathythermograph (XBT) data files.

8. Robinson, Margaret K. Compass Systems Inc., San Diego, California, Consultant.

9. Robinson, Margaret K., 1976. Atlas of the North Pacific Ocean monthly mean temperatures and salinities of the surface layer. Department of the Navy, Naval Oceanographic Office, Washington, D.C.

10. Robinson, Margaret K., and Roger Bauer. Mean deep sea temperature and salinity measurements in the Pacific Ocean based on NODC hydrocast listing 1969. Unpublished.

11. Scripps Institution of Oceanography of the University of California, 1963. Oceanic observations of the Pacific: 1951. Berkeley and Los Angeles, University of California Press.

12. Scripps Institution of Oceanography of the University of California, 1965. Oceanic observations of the Pacific: 1952. Berkeley and Los Angeles, University of California Press.

References (continued)

13. Seckel, Gunther R., 1962. Atlas of the oceanographic climate of the Hawaiian Islands region. U.S. Fish and Wildlife Service, Fishery Bulletin, Vol. 61, No. 193, p. 371-427.